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NOTES

On the Source of Free Ribose formed *post mortem* in the Muscle of Lingcod *(Ophiodon elongatus)* [1]

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ABSTRACT

During the storage of lingcod in ice, the quantities of the ribomononucleotides in the muscle decreased. The decrease was accompanied by an accumulation of free ribose in the muscle. During the same time, no decrease in the ribonucleic acid of the muscle was detected. It was concluded that ribomononucleotides, and not ribonucleic acid, were the precursors of ribose in the muscle *post mortem*.

INTRODUCTION

FISH MUSCLE contains two known sources from which the free ribose that accumulates in some species *post mortem* (Tarr, 1954) might be formed. These are ribonucleic acid (RNA) and certain ribomononucleotides, particularly those of adenine. Tarr (1954) found that free ribose was formed from ribonucleosides, ribomononucleotides, and yeast RNA when these compounds were mixed with ground lingcod muscle, and subsequently some of the enzymes that presumably catalyze the reactions involved have been studied in detail (Tarr, 1955, 1958a; Tomlinson, 1958). In Atlantic codling *(Gadus callarias)* it has been shown that the degradation of ribomononucleotides in the muscle *post mortem* is accompanied by the accumulation of free ribose (Shewan and Jones, 1957), but no report has appeared concerning the fate of RNA in the muscle of this fish. Saito *et al.* (1957, 1959) have studied the course of breakdown of ribomononucleotides in the muscle of carp and rainbow trout, and it is apparent that free ribose may be formed, but whether or not it accumulates does not appear to have been determined. No data regarding RNA in the muscle of these fish *post mortem* are available. Thus, the relative importance of ribomononucleotides and RNA as precursors of free ribose in fish muscle is not known (Tarr, 1958b). Since lingcod *(Ophiodon elongatus)* muscle has been shown to contain enzymes capable of liberating free ribose from either substrate *(vide supra)*, it was selected for use in an investigation to determine their relative importance as precursors of free ribose.

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METHODS AND MATERIALS

Two small lingcod were obtained from the Vancouver Public Aquarium. They were killed by a blow on the head. From one side of the first fish a sample of muscle was at once removed and frozen in liquid nitrogen. Both fish were then gutted and iced. After 4 days in ice, the first fish was removed and a sample of muscle was taken from the previously uncut side. A sample of muscle was removed from one side of the second fish after it had been in ice for 1 day, and a second sample from the uncut side after a further 7 days in ice. All samples were held frozen at −25°C until they were analyzed.

The nucleotides, nucleosides, and purines were extracted from the muscle with ice-cold 5% (w/v) trichloracetic acid (TCA). The quantities of the nucleotides were estimated by the procedure described by Hochster and Madsen (1959). Unidentified, ultraviolet-absorbing materials (not purines or pyrimidines) were present in the extracts, but by the use of both paper chromatographic and paper electrophoretic procedures, interference from these materials was avoided. Inosine and hypoxanthine were separated from the nucleotides by electrophoresis on Whatman No. 3 paper in $0.1M$ ammonium formate buffer, pH 3.5, eluted from the paper, and separated from each other by electrophoresis on Whatman No. 3 paper with $0.1M$ sodium tetraborate, pH 9.2, as buffer (Dimroth *et al.*, 1952). Their quantities were then estimated by the same procedure as that used for the nucleotides. Formate, rather than citrate, buffer was used for the preliminary separation of inosine and hypoxanthine from the nucleotides because it was found that when citrate was used, inosine and hypoxanthine did not separate satisfactorily in the subsequent electrophoretic step. Citrate buffer, however, provided much cleaner separation of the nucleotides from each other than did formate. Adenosine and adenine, if present, are well separated from each other and from inosine, hypoxanthine, and the nucleotides by electrophoresis at pH 3.5. The sensitivity of the method was such that if a nucleotide, nucleoside, or purine was present in the muscle at a concentration of less than about 0.03 to 0.04 micromole (μM) per gram, it would not be detected.

Ribose was determined by the method of Jones (1958) and RNA by a modification of the Schmidt and Thannhauser (1945) procedure previously described (Creelman and Tomlinson, 1959).

RESULTS AND DISCUSSION

The experimental results are presented in Table I. It is evident that RNA could not have contributed any important part of the ribose that accumulated. The apparent small decrease in RNA in Fish No. 1 is no greater than the difference found by Creelman and Tomlinson in 1959 (unpublished data) between determinations of RNA made from separate samples of muscle taken at one time from a single lingcod.

TABLE I. Ribomononucleotides and RNA as sources of free ribose in muscle of lingcod stored in ice.

Compound	Quantity[a] of compound[b] found per gram wet muscle			
	Fish No. 1		Fish No. 2	
Days stored:	0	4	1	8
	μM	μM	μM	μM
ATP	0.53	—	—	—
ADP	0.31	0.32	0.32	0.27
AMP	0.03	—	—	0.3
IMP	3.89	3.20	5.39	0.98
Inosine	0.25	—	—	—
Hypoxanthine	—	1.67	—	1.79
Ribose	0	0.9	trace	4.0
RNA-P	1.9	1.7	0.82	0.83

[a]A dash indicates that none of the compound was detected. If it was present in the muscle, it must have been at a concentration of less than 0.04 $\mu M/g$.

[b]ATP, ADP, AMP, IMP, and RNA-P are abbreviations for adenosine triphosphate, adenosine diphosphate, adenosine monophosphate, inosine monophosphate, and ribonucleic acid-phosphorus, respectively.

In separate work, degradation of RNA could not be detected either in lingcod held in ice, or in sterile lingcod muscle held at 0°C, for a period of 3 weeks (Tomlinson *et al.*, 1960).

The stability of RNA in the muscle was unexpected in view of earlier findings (Tarr, 1954). As was pointed out above, lingcod muscle contains an enzyme system that can degrade RNA prepared from the muscle (Tomlinson, 1958) and the work of Tarr (1954) indicates that its inability to degrade the RNA as it occurs in the muscle cannot be due to inhibition of the enzyme. The possibility that it might be necessary to grind the flesh, as Tarr did, before breakdown of tissue RNA could proceed was investigated, and it was found that no breakdown of RNA could be detected in ground muscle after 5 days storage at 0°C. Several explanations of the inability of the muscle enzymes to degrade tissue RNA *post mortem* suggest themselves. Possibly the enzyme and RNA do not come into contact with each other, or perhaps the RNA is protected from attack through association with protein (Hamoir, 1951). Another possibility, and perhaps the most likely one, is that the RNA as it exists in the muscle is not susceptible to attack by the enzyme, but that during the process of isolation and purification it becomes modified (perhaps through some degree of depolymerization) in such a manner that it can then be attacked by the enzyme.

Referring again to Table I, it is clear that there was a very large decrease in the quantity of the ribomononucleotides during storage of the fish in ice, and that this decrease was accompanied by an accumulation of free ribose in the muscle. There can be no doubt that ribomononucleotides, and not RNA, were the main precursors of the ribose that accumulated.

It is interesting that neither adenosine nor adenine was detected in TCA muscle extracts during this work.

ACKNOWLEDGMENT

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The Macroscopic Bottom Fauna of Lac la Ronge, Saskatchewan[1,2]

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ABSTRACT

In the summers 1948 to 1953 (except 1951) 796 quantitative dredge samples were taken in the main lake and 172 in Hunter Bay. The 1948 and 1949 populations of the main lake were significantly higher than the 1952 and 1953 populations. No significant yearly difference occurred in Hunter Bay. The amphipods (mainly *Pontoporeia affinis*) predominated in the oligotrophic Hunter Bay which had 2192 organisms per square metre and dry weight of 6.4 lb per acre. The chironomid larvae (mainly *Chironomus anthracinus*) predominated in the mesotrophic main lake which had 742 organisms per square metre (7.9 lb/acre, 8.8 kg/ha). The depth distribution of the main groups are given. Correlation of depth with numbers was shown. Numbers in the main lake showed spring and fall maxima, with a summer minimum. The yearly variation was greatest in the chironomid larvae. The ooze type in the upper littoral had the greatest number of organisms. An annotated species list of some groups is given.

INTRODUCTION

LAC LA RONGE, which lies on the edge of the Precambrian Shield in north-central Saskatchewan, has an area of 500 sq mi (1300 sq km) and a maximum depth of 42 metres. The depth contours at 5-metre intervals are shown in Fig. 1. Two well defined natural areas are distinguished, the main lake and Hunter Bay. The main lake can be subdivided into two physiographic regions; the open water region (area 160 sq miles, 415 sq km) with a shallow gradually sloping basin and the island region (area 290 sq miles, 750 sq km) with a deeper and highly irregular bottom. Additional information on the physiography of this lake is given by Rawson and Atton (1953).

A large number of dredgings, taken in Lac la Ronge from 1948 to 1950, by field parties supervised by Dr Rawson, were made available to the author. Analysis of the bottom organisms showed that more organisms appeared to be present in 1950 in the main lake than in the two previous years. An attempt was made to duplicate the sampling in 1952 and 1953, in order to make a comparison with these years. In 1952, samples were taken over the whole area of the lake as in 1948 to 1950, but most of the sampling was restricted to 5 series and 4 stations (Fig. 1). The series were sampled monthly and two dredgings were taken every 10 to 14 days at the stations. This was continued in 1953, and 91 samples were taken in the 0–1.0-metre zone. This zone was classified into 5 types: exposed rock, protected rock, exposed sand, protected sand and ooze (usually with rooted aquatic plants). In each of the three major regions of the lake, an area (if present) representing each of the above types was selected and sampled repeatedly.

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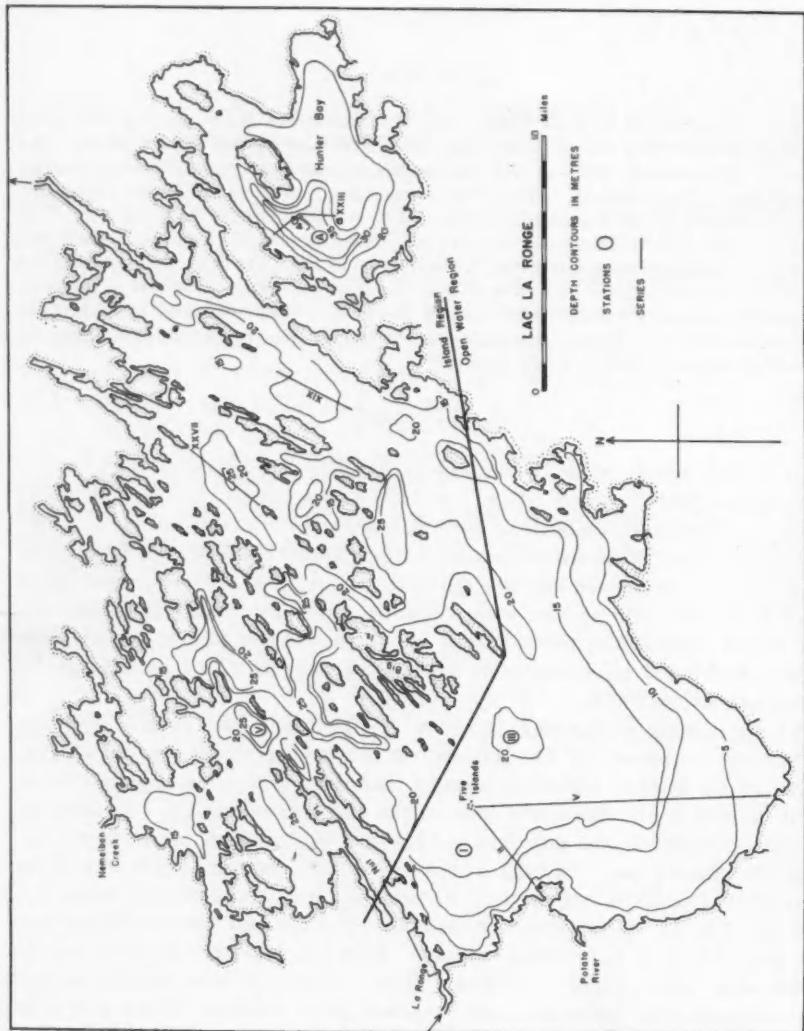
Fig. 1.   Map of Lac la Ronge showing depth contours, stations, dredging series, and the dividing line between the open water region and the island region.

Large (used almost exclusively in 1948 to 1950) and small Ekman dredges, a Petersen dredge and a Unit Area Sampler were used to take the samples. Hess (1941) described a sampler somewhat similar to the Unit Area Sampler. It was made from a strong steel cylinder 85 cm high and enclosed an area of 1110 sq cm. A pair of handles made it possible to insert the cylinder by rotary movement until the edges were tightly wedged in stone or gravel bottoms. The loose material was picked out by hand accompanied by a screen-bottomed dipper and transferred to a dredge bucket.

Three screens, of the same mesh size described by Rawson (1930) were used to wash the dredgings. Only the top two screens were used to sort dredgings from the main lake, and all three for those from Hunter Bay. When the two areas are directly compared appropriate corrections are made in the numbers. This correction is based on the results from analyzing separately the organisms retained by the top two screens in the dredgings from Hunter Bay.

YEARLY VARIATION OF THE BOTTOM POPULATION

The mean number of organisms per dredging (large Ekman) for 4 years in the main lake are the following:

> 1948—39.60 organisms per dredging (215 dredgings)
> 1949—43.62 organisms per dredging (175 dredgings)
> 1952—27.07 organisms per dredging (188 dredgings)
> 1953—29.65 organisms per dredging (215 dredgings)

Figure 2 shows that the reduction in numbers in the last 2 years was consistent in the majority of the depth zones.

The data from each year were grouped into depth zones for the two regions. The logarithms of numbers of the total counts were treated by analysis of variance, with the appropriate corrections for unequal subclass numbers. The results of the analysis were $F = 3.0808/0.1368 = 22.52$, $F_{0.01} = 3.80$, with the least significant difference $= 7.18$ organisms per dredging. Referring to mean number of organisms per dredging given above, this statistical analysis indicates that the years 1948 and 1949 were significantly different from 1952 and 1953. No significant difference was found between 1948 and 1949, and none between 1952 and 1953.

As most of the samples taken in the latter 2 years were restricted to specific areas, whereas in 1948 and 1949 they were distributed over the whole lake, the possibility that this difference in the distribution of samples caused the above variation must be considered. If dredgings were taken from the same location in the lake and sampled several times each year, this probable source of error would be eliminated. Dredging data from series II, V, XIX and XXVII satisfy this requirement and these series are regarded as being representative of most of the bottom in the main lake. Therefore changes in the bottom population should be reflected in these series. The data from 1950 are also included in the analysis.

The results were $F = 1.461/0.147 = 9.938$, $F_{0.01} = 3.41$, with the least
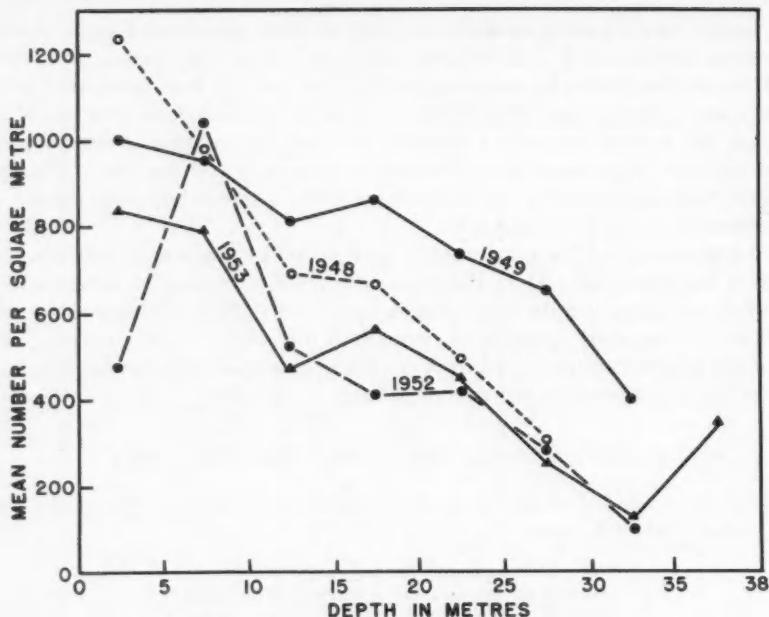
FIG. 2.   Numerical distribution of bottom organisms with depth in 1948, 1949, 1952 and 1953 in the main lake, Lac la Ronge.

significant difference = 4.70 organisms per dredging. Comparing the mean number of organisms per dredging for the 5 series:

1948—37.50 organisms per dredging (41 dredgings)
1949—41.77 organisms per dredging (53 dredgings)
1950—54.46 organisms per dredging (52 dredgings)
1952—21.16 organisms per dredging (51 dredgings)
1953—22.13 organisms per dredging (31 dredgings)

the previous conclusion about year-to-year variation is supported. The mean number of organisms in 1950 was significantly higher than all other years.

Figures 4 and 5, below, show that the greatest reduction in numbers occurred in the chironomid larvae, although some of the other groups also exhibited a reduction. As the chironomid curve is governed primarily by one species, *Chironomus anthracinus*, and this spends part of its life cycle out of the water, yearly variation in its numbers might be expected if unfavourable environmental conditions are met during the emergence and egg-laying periods.

The total weights from the main lake were similarly analysed and the 1952 and 1953 weights were also significantly lower.

Series XXIII, representing the deeper part of Hunter Bay, was analyzed in a similar manner. The results for numbers are $F = 25.849/6.753 = 3.83$, $F_{0.01} = 4.13$; and for weights, $F = 0.038/0.197 = 1.93$, $F_{0.01} = 4.13$. These show no significant difference between years.

In accordance with the above analysis the data from 1948 and 1949 are grouped and considered as taken from a single population—the 1948–49 population. Similarly the data from 1952 and 1953 are grouped as the 1952-53 population. All the data from Hunter Bay are regarded as taken from a single population different from the above two.

DISTRIBUTION IN AREA AND DEPTH

The populations of the main lake and Hunter Bay differ both in the numbers and composition of organisms, although the total weights are similar (main lake, 7.03 kg/ha and Hunter Bay, 5.7 kg/ha). The mean number of organisms per square metre in Hunter Bay was 2192, approximately 3 times the main lake figures—831 in 1948–49 and 568 in 1952–53. Chironomid larvae (mostly *Chironomus anthracinus*), the commonest organisms in the main lake, comprise 52% of the total numbers, but made up only 4.2% in Hunter Bay. Similarly the amphipod *Pontoporeia affinis*, the commonest organism in Hunter Bay (60.4%), occurred in much smaller numbers in the main lake (17.0 and 15.8%).

Figure 3 shows the depth distribution of the mean number and the mean wet weight, in each 5-metre depth zone, of all organisms in the two populations of the
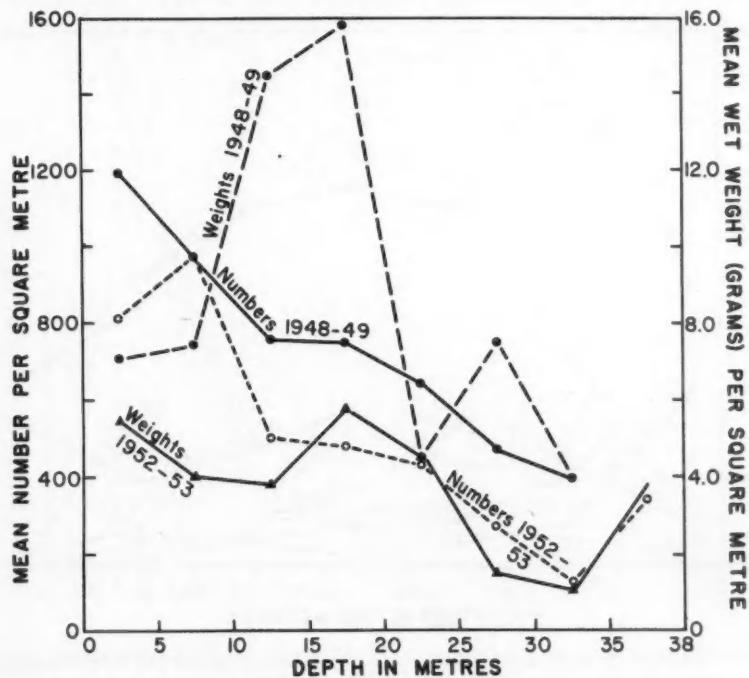
FIG. 3. Comparison of the depth distribution of weights and numbers of the bottom organisms in the 1948–49 and 1952–53 populations of the main lake, Lac la Ronge.

main lake.   The numbers in the 1948–49 population decreased fairly uniformly
from a maximum of 1195 per square metre.   The 1952–53 population differed
in that the numbers increased from 811 to 970/m² in the first two depth zones,
then dropped to 134/m² in the 30–35-metre zone.   In sampling the 1948–49
population a disproportionately large number of samples were probably taken in
the ooze bottom type of the littoral zone, as the large Ekman dredge was used
almost exclusively.   Below it is shown (Table VI) that the ooze type in the
upper littoral had a greater number of organisms per square metre than the other
types.   The ooze type comprises quite a small proportion of the upper part of the
littoral.   Furthermore the figures for 1952 and 1953 in this zone were calculated
by weighting the data on the basis of percentage area each type contributed to
the total area.   It is therefore probable that the 0–5-metre zone has a lower
number of organisms than the next zone.

The weight curves in Fig. 3 do not parallel the trend of the number curves
for each population.   A more definite correlation between weights, numbers and
depth might be expected.   It is shown below that the mean weight of all organisms
per square metre differed considerably between the open water region and the
island region.   Combining the weights from the two regions might mask any
definite relationship.   It may also be important to consider each group separately.
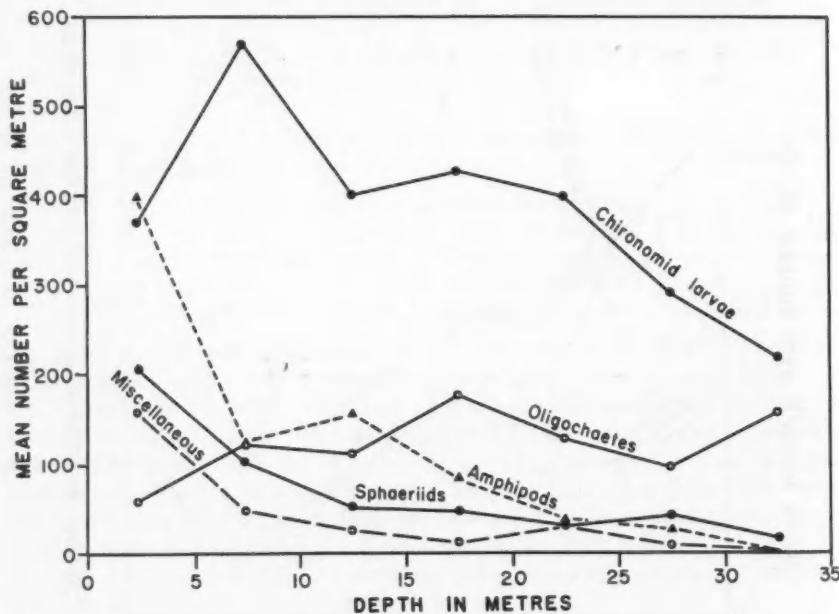
FIG. 4.   Details of the depth distribution of bottom organism groups for the 1948–49 population
in the main lake, Lac la Ronge.

Figures 4 and 5 show the depth distribution for the chironomid larvae, amphipods, oligochaetes, sphaeriids and miscellaneous groups (the remaining organisms listed in Table VI) for both populations of the main lake. The chironomid larvae, which generally controlled the shape of the total-numbers curves, exhibit similar distributions for both populations. The amphipods, oligochaetes and sphaeriids show more or less the same distribution with depth in each population. Only in the 0–5-metre zone do the curves differ greatly. With a preponderance of ooze type samples, as suggested above, the discrepancy is partly explained.

There is a rise in total numbers in the deepest part of the main lake (not sampled in 1948–49). This area, located 2 miles southwest of the tip of Nut Point, is about 0.1% of the total area of the main lake. In 1952 and 1953 it was sampled in duplicate several times each season and the numbers of organisms were consistently higher than in the 25–35-metre zones. The chironomid larvae and the amphipods were each represented by a single species, *Chironomus anthracinus* and *Pontoporeia affinis*.

Comparison of the weighted average numbers per square metre between the island region and the open water region (Table I) indicated only a slight difference between the two regions, but the average weight of organisms per square metre
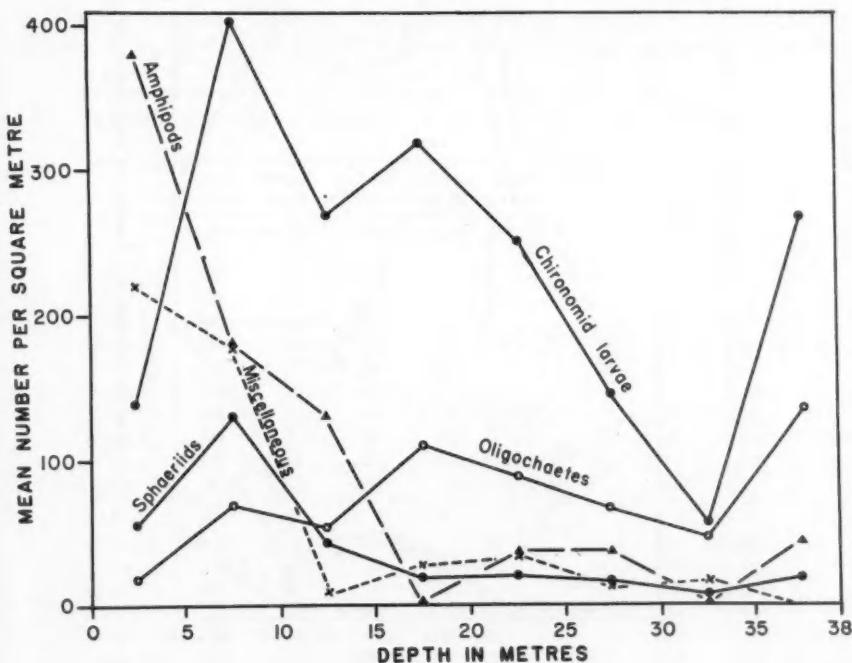
FIG. 5. Details of the depth distribution of bottom organism groups for the 1952–53 population in the main lake, Lac la Ronge.

TABLE I. Weighted mean values for total numbers of organisms per square metre, and total dry weights (kilograms per hectare) for the two regions in the main lake.

	Number of organisms		Weight of organisms	
Region	1948–49	1952–53	1948–49	1952–53
	no./m²	no./m²	kg/ha	kg/ha
Open water region	823	736	10.4	7.4
Island region	826	647	3.7	2.0
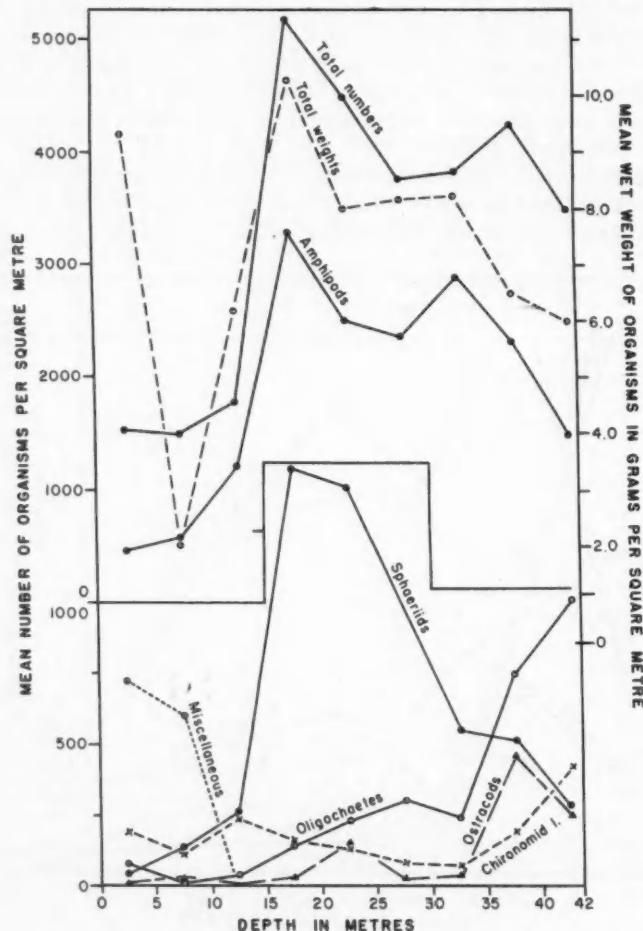
FIG. 6. Details of the depth distribution of the bottom organisms, 1948–53 (except 1951), Hunter Bay, Lac la Ronge.

was much less in the island region. The island region is deeper than the open water region, but the percentage of the bottom deeper than 22 m (the deepest in the open water region) is small, approximately 3.5%. Even though the mean weight of an organism decreased below this depth, the inclusion of these data is not expected to lower the weight of organisms to the degree shown in Table I. This suggests that the trophic conditions of the open water region allow the organisms to grow larger, but it also suggests that the method of analysis where all groups of organisms are treated as a unit may not be satisfactory.

Figure 6 shows the depth distribution of the mean number and mean net weight of organisms and the numbers per square metre of the various groups in Hunter Bay. There is a close similarity in the curves for numbers and weights, except in the first 2 metre zones. Most of the littoral of Hunter Bay slopes down very rapidly, making it difficult to obtain samples, which may be the cause of the lack of relationship between the curves. The amphipods govern the trend of the numbers curve. As in the main lake, the numbers of chironomid larvae and oligochaetes rise in the deepest part of the Bay, but amphipods and sphaeriids do not.

SEASONAL VARIATION BELOW THE LITTORAL

The results of the duplicated sampling at Stations I, III, and V in 1952 and 1953 are to be found in Tables II, III and IV. A summer minimum occurred

TABLE II. Seasonal variations in the mean numbers and weight of various groups or organisms, per square metre, at Station I, main lake, in 1952 and 1953.

Date	Chiro-nomids	Oligo-chaetes ·	Sphae-riids	Amphi-pods	Ostra-cods	Nema-todes	All organisms	
	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	g/m^2	
1952								
May 20	520	40	150	...	...	...	710	13.52
June 6	720	120	190	...	...	...	1030	11.22
June 18	300	100	320	...	...	...	720	3.08
June 25	130	20	140	80	...	60	430	2.80
July 7	190	20	160	150	...	20	540	1.30
July 18	250	20	110	50	...	...	430	1.68
July 30	200	20	60	60	420	...	760	1.80
Aug. 12	390	20	70	80	850	...	1410	1.08
Aug. 27	870	40	90	60	1280	...	2340	2.08
Sept. 9	700	80	240	30	1780	...	2830	3.84
1953								
May 25	400	...	40	20	...	...	460	5.22
June 3	470	50	80	10	...	...	610	4.78
June 22	280	60	10	60	...	...	410	2.68
July 22	150	90	20	40	...	...	300	0.92
Aug. 5	250	50	40	90	...	...	430	1.28
Aug. 18	240	60	20	...	...	...	320	0.44
Aug. 24	160	...	10	...	...	...	170	0.72
Sept. 3	760	20	10	20	...	...	810	3.22

TABLE III. Seasonal variation in the mean numbers and weight of various groups of organisms, per square metre, at Station III, main lake, 1952 and 1953.

Date	Chiro-nomids	Oligo-chaetes	Sphae-riids	Amphi-pods	Gastro-pods	Nema-todes	Ostra-cods	All organisms	
	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	g/m^2
1952									
May 23	250	70	10	20	. . .	. . .	. . .	350	6.00
May 30	370	190	30	. . .	. . .	. . .	. . .	590	5.66
June 6	160	100	. . .	. . .	. . .	. . .	. . .	260	0.94
June 25	80	150	10	. . .	. . .	. . .	. . .	240	1.06
July 7	90	40	. . .	10	20	. . .	. . .	160	0.56
July 18	. . .	40	10	. . .	. . .	. . .	. . .	50	1.80
July 30	170	100	50	. . .	. . .	10	50	380	0.36
Aug. 13	180	70	80	. . .	. . .	. . .	450	780	0.14
Aug. 27	100	30	. . .	. . .	. . .	. . .	40	170	1.04
Sept. 7	160	20	20	. . .	. . .	. . .	70	270	2.74
1953									
May 25	900	40	30	. . .	. . .	. . .	. . .	970	13.84
June 3	590	30	20	. . .	. . .	. . .	. . .	640	10.64
June 22	240	. . .	20	. . .	. . .	. . .	. . .	260	3.84
June 29	250	100	10	10	. . .	. . .	. . .	370	7.14
July 11	420	80	40	. . .	. . .	. . .	. . .	540	10.04
July 22	290	50	20	60	. . .	. . .	. . .	420	7.08
Aug. 5	280	40	. . .	10	. . .	. . .	. . .	330	3.90
Aug. 15	330	110	10	. . .	. . .	. . .	. . .	450	10.12
Aug. 24	160	50	10	. . .	. . .	. . .	. . .	220	5.56
Sept. 8	230	70	. . .	. . .	. . .	. . .	. . .	300	1.97

TABLE IV. Seasonal variations in the mean numbers of various groups of organisms per square metre at station V, Lac la Ronge, 1952 and 1953.

Date	Chiro-nomids	Oligo-chaetes	Sphae-riids	Amphi-pods	Ostra-cods	All organisms	
	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	g/m^2
1952							
May 28	40	50	20	. . .	. . .	110	0.29
June 18	100	40	20	. . .	. . .	160	1.48
June 28	130	30	. . .	10	. . .	170	1.09
July 18	60	80	40	260	. . .	440	1.08
July 23	80	. . .	20	40	. . .	140	0.42
Aug. 11	30	70	. . .	. . .	20	120	0.90
Aug. 21	30	. . .	10	20	. . .	60	0.19
Sept. 5	. . .	140	. . .	. . .	. . .	140	0.82
Sept. 11	. . .	20	. . .	. . .	. . .	20	0.15
1953							
May 26	90	50	10	. . .	. . .	150	2.01
June 5	70	220	10	10	. . .	310	1.44
June 20	40	40	20	. . .	. . .	100	2.14
June 30	50	. . .	. . .	. . .	. . .	50	1.48
July 10	90	70	20	. . .	. . .	180	3.41
July 22	20	40	. . .	. . .	. . .	60	0.81
Aug. 6	90	30	. . .	. . .	. . .	120	0.57
Aug. 24	90	20	. . .	. . .	. . .	110	1.73
Sept. 9	30	40	. . .	. . .	. . .	70	0.42

between the spring and fall maxima. When the data from the 3 stations are considered together, the amplitude of this fluctuation becomes smaller with increasing depth. Usually the seasonal variation of the chironomid larvae determines the variation of the total numbers, and as the chironomid larval fraction of the total numbers was less at Station V, the relative stability of the other groups masked the variation of the chironomid larvae.

In late July, 1952, large numbers of ostracods appeared and increased until
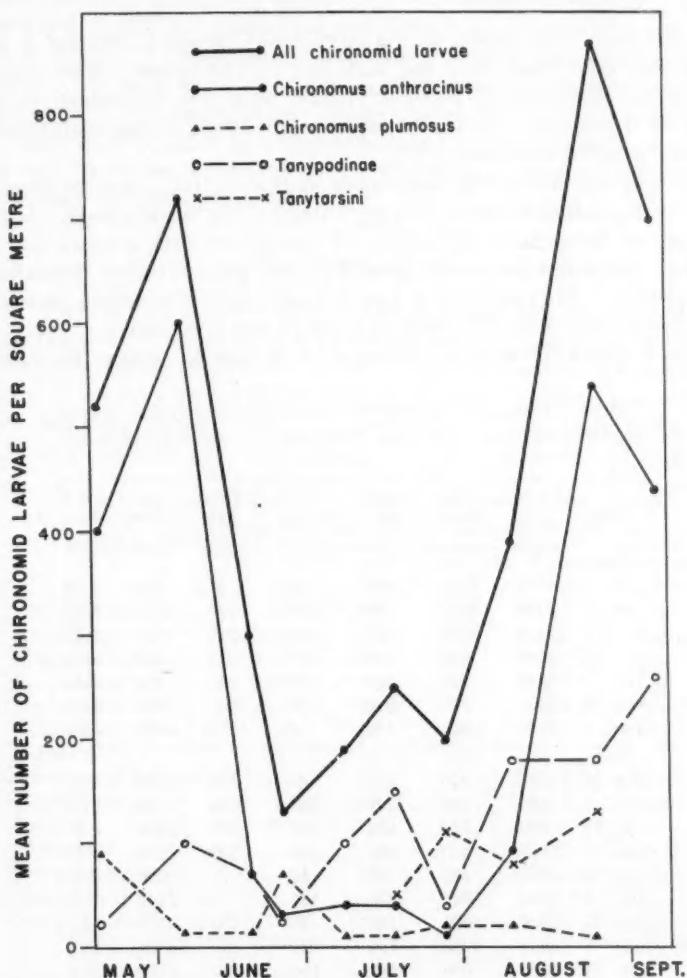
FIG. 7. Seasonal variation of chironomid larvae, Station I, 1952, in the main lake, Lac la Ronge.

September at Station I.   Ostracods also appeared at this time at Station III.
Examination of the bottom sediments from Station I in 1953 showed ostracods
were present, but of small enough size to pass through the dredging screens.
The ostracods in Hunter Bay rarely reached this size.

The oligochaetes at Station I exhibited little variation and their contribution
to the seasonal fluctuation in numbers was negligible.   In both years the amphi-
pods (*Pontoporeia affinis*) showed a maximum about the first of July and then
gradually declined in numbers.   The sphaeriids generally showed an irregular
seasonal variation.

The seasonal fluctuation of the chironomid larvae at Station I in 1953
(Fig. 7) was little more than the variation in *Chironomus anthracinus*.   The
larvae of the Tanypodinae and Tanytarsini were not determined to species.
Each of these consisted of several species and occurred in too small numbers to
reveal any seasonal variation.

This was also true of the amphipods at Station III.   Several times, when
this station was sampled, amphipods were absent from the dredgings.   Dredgings
were taken in the vicinity of Station III throughout both seasons, and it was
established that amphipods were present in the general region throughout the
sampling period.   They were few in numbers and appeared to have a discontinuous
distribution as they were not found in many of the dredgings.

Table V shows the seasonal variation at Station A.   Again the commonest

TABLE V. Seasonal variation in the mean numbers of various groups
organisms per square metre at station A, Lac la Ronge, 1952 and
1953.

Date	Amphi-pods	Oligo-chaetes	Sphae-riids	Chiro-nomids	Ostra-cods	All organisms	
	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	$no./m^2$	g/m^2
1952							
June 3	1020	1040	840	240	20	3160	2.38
June 27	4250	4460	990	210	230	10140	8.32
July 9	2440	1260	370	480	360	4910	5.53
July 22	1260	840	600	340	620	3660	7.03
Aug. 8	4240	940	660	100	240	6180	7.04
Aug. 20	2120	760	1020	100	1800	5800	4.24
Sept. 5	2170	870	250	110	1070	4470	4.36
1953							
May 26	1380	420	740	40	730	3310	4.86
June 4	2680	380	530	340	190	4120	5.85
June 19	580	740	480	260	740	2800	4.40
June 29	880	610	410	150	330	2380	4.66
July 3	2500	460	180	180	...	3320	4.70
July 9	3860	940	220	220	...	5240	7.39
July 24	1800	1030	280	180	210	3500	6.17
Aug. 5	2860	1060	130	130	380	4560	9.81
Aug. 13	3020	660	880	160	1760	6480	5.46
Aug. 26	1780	600	590	180	1860	5010	6.40
Sept. 9	2130	400	230	310	810	3880	8.79

organism, *Pontoporeia affinis* governed the trend of the mean number curve. There is no seasonal pattern common to both years. The variation of the chironomid larvae, primarily *Chironomus anthracinus*, was somewhat similar to that in the main lake in 1953. In 1952 the peak occurred later than in 1953, and presumably the sampling did not continue long enough for the second peak to occur.

The above results indicate that two samples are sufficient to demonstrate seasonal variation in common species like *Chironomus anthracinus*. However the numbers of the component groups often vary greatly between the two dredgings of a pair. This suggests the distribution of at least some of the groups is uneven. The good trends obtained for *Chironomus anthracinus* suggests that it had a fairly regular distribution. When uneven distribution is combined with small numbers, there must be considerable areas in which a particular species is absent, and to obtain a good picture of its seasonal variation the numbers of samples must necessarily be large.

THE UPPER LITTORAL

The upper metre of the littoral in Lac la Ronge was divided into 5 types (see Introduction). The exposed type was subject to strong wave action and the protected type to only gentle wave action. The areas selected for sampling were distinctly of one type or the other, although areas occur which are intermediate between the two types. Table VI presents the results from sampling these upper littoral types in the main lake. The protected rock and exposed sand

TABLE VI. Comparison of the mean numbers of organisms, per square metre, in the upper littoral shore types of the main lake in 1953.

	Ooze	Exposed rock	Protected sand	Exposed sand	Protected rock
No. of dredgings	6	30	14	13	5
Amphipods	4113	107	325	97	80
Chironomid larvae	617	151	116	55	136
Sphaeriids	267	7	17	157	44
Gastropods	428	272	6	18	48
Oliogochaetes	60	18	4	17	4
Ostracods	20	4	141	58	...
Mayfly nymphs	23	16	23	8	32
Caddisfly larvae	7	37	...	5	80
Leeches	23	11	1	15	...
Nematodes	...	...	...	40	...
Ceratopogonids	...	16	...	5	8
Tabanids	...	...	3	...	...
Total numbers	5558	639	636	475	432

types together make up about 95% of the upper part of the littoral zone in the main lake, with the former more common in the island region.

The *ooze* type, found at the end of well sheltered bays, was only rarely

subjected to wave action and contains a very large number of organisms: Amphipods, averaging 4113/m², comprised 74% of the total numbers. Chironomid larvae, mollusca and oligochaetes were more numerous in this type than in any other.

Gastropods were most common in the second ranking type, *exposed rock*. Sphaeriids were very rare in this type, presumably because of the difficulty in maintaining their position during strong wave action. A small percentage of this type was a fairly smooth, unbroken rock. The fauna here was only investigated qualitatively, and generally only gastropods and tube-building chironomid larvae were found.

The commonest organisms in the *protected sand* type were the amphipods, ostracods and chironomid larvae, with the other groups occurring in small numbers. *Exposed sand* had the greatest variety of groups.

Insect larvae predominated on the *protected rock* type of littoral; chironomid larvae, caddisfly larvae, mayfly nymphs and ceratopogonid larvae made up about 60% of the total numbers. However amphipods, with the caddisfly larvae, ranked second in numbers to the chironomids.

In Hunter Bay the upper littoral is composed almost entirely of exposed rock, with less than 1% ooze and protected rock. Only the ooze and exposed rock were investigated (Table VIII). The exposed rock in Hunter Bay had more

TABLE VII. Mean numbers per square metre of all groups of organisms in the littoral shore types of Hunter Bay in 1953.

	Ooze	Exposed rock
Number of dredgings	11	6
Amphipods	891	67
Chironomid larvae	142	17
Sphaeriids	29	. . .
Gastropods	35	450
Oligochaetes	96	13
Ostracods	. . .	. . .
Mayfly nymphs	35	30
Caddisfly larvae	4	257
Leeches	11	27
Nematodes	2	. . .
Tabanids	5	. . .
Donacia sp.	24	. . .
All organisms	1274	861

organisms than in the main lake, but the ooze type had much fewer. This is in contrast to the general condition existing between the entire areas of the two sections of the lake. As in the main lake, the amphipods and chironomid larvae are the commonest organisms in the ooze type, but the caddisfly larvae are proportionately much more common in the latter type in Hunter Bay. The absence of ostracods from the upper littoral samples was notable, since they reach concentrations up to 400/m² in the deeper regions of the bay.

ACKNOWLEDGMENTS

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APPENDIX: ANNOTATED LIST OF BOTTOM ORGANISMS

Representatives of 6 metazoan phyla, Porifera, Coelenterata, Nemathelminthes, Annelida, Mollusca and Arthropoda have been found in the macroscopic bottom fauna of Lac la Ronge. Of these, the last 4 phyla were commonly taken by dredging.   Both in number of species and number of individuals, the Mollusca and the Arthropoda were the commonest organisms.

HIRUDINEA

The leeches have been identified by Dr J. P. Moore of the University of Pennsylvania, and were previously listed by Oliver (1958).

Glossiphonia complanata (Linn.)   Common in shallow regions of the lake with much organic debris.

Helobdella stagnalis (Linn.)   This is the most common leech in Lac la Ronge.   During the day it is found resting among bottom debris and rocks.

Piscicola punctata Verrill.   Commonly found attached to the gills, fins and tail of the pickerel (*Stizostedion vitreum*) and of the jackfish (*Esox lucius*).   It has been taken in dredgings down to a depth of 36 m in Hunter Bay and 17.5 m in the main lake.

Haemopis grandis (Verrill).   A very large leech, often seen swimming with a characteristic undulating motion in the shallower regions of the lake.

Erpodbella punctata (Leidy).   One specimen taken in a small bay with a bottom composed of sand and gravel in the island region.

Nephelopsis obscura Verrill.   Several specimens were found under leaves and stones in sheltered bays in the open water region.

MYSIDACEAE

Mysis relicta Lovén.   Occasionally taken in dredgings in the open water region and in Hunter Bay.

AMPHIPODA

Gammarus lacustris Sars.   Common down to ten metres.

Hyalella azteca (Saussure).   Found only in shallow protected bays.

Pontoporeia affinis Lind.   This species was the predominant organism in Hunter Bay and ranked second in numbers in the main lake.

EPHEMEROPTERA

The mayfly adults have been identified by Dr F. P. Ide of the University of Toronto.

Blasturus nebulosus Walker

Caenis latipennis Banks

Callibaetis near *ferrugineus* Walsh

Ephemera simulans Walker

Hexagenia occulta Walker

Stenonema interpunctatum group

S. tripunctatum Banks

Siphlonurus alternatus Say

Nymphs of the genera *Ephemera* and *Hexagenia* were common in the lake.   Mayfly nymphs, from 54/m² in the 0–5-metre zone, decreased to 18/m² at 5–10 m and to 0.14/m² at 10–15 m in the main lake.

TRICHOPTERA

Adults of 35 species have been identified by Dr H. H. Ross of the State Natural History Survey, Urbana, Illinois.   Most of these were collected within 2 or 3 miles of the La Ronge townsite.

Agrypnia colorata Hagen

A. improba (Hagen)

A. straminea Hagen

Athripsodes alagmus Ross

A. ancylus (Vorhies)

A. dilutus (Hagen)

A. miscus Ross

A. tarsipunctatus (Vorhies)

Cheumatopsyche analis (Banks)

Helicopsyche borealis Hagen

Hesperophylax incisus Banks

Hydropsyche bifida Banks

H. occidentalis Banks

H. recurvata Banks

Lepidostoma strophis Ross

L. togatum Hagen

Leptocella albida (Walker)

Limnephilus batchewana Denning

L. extractus Walker

L. infernalis Banks

Molanna flavicornis Banks

Mystacides longicornis (Linn.)

M. sepulchralis (Walker)

Nyctiophylax vestitus (Hagen)

Oecetis avara (Banks)

Oe. inconspicua (Walker)

Oe. ochracea (Curtis)

Oxyethira serrata Ross

Phryganea cinerea (Walker)

Platycentropus plectrus Ross

Polycentropus cinereus Hagen

Psychomyia flavida Hagen

Ptilostomis semifasciata (Say)

Pycnopsyche guttifer (Walker)

Triaenodes frontalis Banks

Caddis fly larvae averaged 33/m² in the 0–5-metre zone.   Below 5 m their numbers were very small.   The greatest number of these larvae was found in the protected rock upper littoral type, then in the exposed rock type.   Identification of the larval material is possible to family, and in some instances to genus and species.

Athripsodes sp.   Inlet of Nemeiben Creek.   Exposed rock.

Cheumatopysche sp.   Nut Point.   Exposed rock.

Helicopsyche borealis Hagen.   Inlet of Nemeiben Creek.   Exposed rock.

Hydropsyche spp.   Common in the island region and in Hunter Bay.   Exposed rock.

Lepidostoma sp.   Inlet of Potato River.   Protected sand.

Limnephilidae. Big Island. Exposed rock.
Limnephilus sp. Potato Point. Ooze.
Molanna sp. Common in both protected rock and ooze shore types in the main lake.
Oecetis sp. Five islands. Exposed rock.
Phryganeidae. Main lake. Ooze and exposed rock.
Polycentropus sp. Main lake. Ooze and exposed rock.
Psychomyia flavida Hagen. Five islands. Exposed rock.

ODONATA

Adults of eight species were identified by Dr E. M. Walker of the Royal Ontario Museum at Toronto.

Aeschna eremita Scudder
Ae. interrupta lineata Walker
Ae. umbrosa Walker.
Cordulia shurtleffi Scudder. Abundant June 18–21, 1951.
Enallagma clausum Morse
Leucorrhinia hudsonica Selys
Sympetrum internum Montg.
Tetragoneuria spinigera Selys. Abundant June 18–21, 1951.

Nymphs of Odonata (genera *Aeschna* and *Sympetrum*) were collected in shallow bays around the edge of Lac la Ronge.

COLEOPTERA

Donacia sp. Several larvae were found in a shallow bay in Hunter Bay.

CERATOPOGONIDAE

These were identified by Mr J. A. Downes, Science Service, Ottawa.
Culicoides obsoletus (Meigen) or a close relative.
Palypomia-group, larvae which are most probably *Bezzia* sp.

CHIRONOMIDAE

Only a few of the 44 species collected in the Lac la Ronge area are listed here. The species of *Brillia* and *Stictochionomus* are new to North America.

Chironomus anthracinus Zett.
Chironomus decorus John.
Chironomus plumosus Linné
Chironomus staegeri Lund.
Brillia longifurca Kieff.
Sergentia coracinus Zett.
Stichtochironomus rosenschöldi (Zett.)

GASTROPODA

The taxonomy and ecology of the Lac la Ronge gastropods are being investigated by Mr A. R. Murray. The following schedule shows the mean number of gastropods in each depth zone down to 25 m, the deepest they occurred in the main lake.

Depth zone, m	Mean number per m²
0–5	63
5–10	17
10–15	1
15–20	2
20–25	0.6

The following gastropods have been identified by Dr D. W. Taylor, University of Michigan.

Amnicola limosa (Say)
Discus cronkhitei (Newc.)
Gyraulus deflectus (Say)
Gyraulus parvus similaris (F.C.B.)
Helisoma pisbryi infracarinatum (F.C.B.)
Limnaea obrussa Say
Limnaea palustris Mull.
Limnaea stagnalis (Linn.)
Physa gyrina Say
Planorbella armigera (Say)
Promenetus exacuous (Say)
Succinea sp.

PELYCOPODA

The following species have been identified by the Reverend H. B. Herrington of Keene, Ontario.

Pisidium casertanum (Poli).   Common, in shallow water.
Pisidium compressum Prime.   Rare, in shallow water.
Pisidium ferrugineum Prime.   Common.
Pisidium lilljeborgi Clessin.   Common, especially in deep water.
Pisidium mainense Sterki.   Scarce.
Pisidium milium Held.   Few, in shallow water.
Pisidium nitidum Jenyns.   Very common in both shallow and deep water.
Pisidium obstusale Pfeiffer.   Common, in shallow water.
Pisidium pauperculum Sterki.   Rare, in shallow water.
Pisidium subtruncatum Malm.   Common in shallow and deep water.
Pisidium variabile Prime.   Common in shallow water.

A History of the Lake Winnipeg Fishery for Whitefish, *Coregonus clupeaformis*, With Some Reference to its Economics[1]

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ABSTRACT

The evolution of the Lake Winnipeg whitefish fishery with respect to location, catch, boats and gear is traced from 1883 to 1958. Economic factors affecting fishing techniques and which have implications in management are indicated.

INTRODUCTION

RECENT PAPERS concerning Lake Winnipeg commercial fisheries (1, 2) deal mainly with the subject from the insular point of view of the biologist. During their researches, many data were recorded by these authors which, although pertinent, were of a general nature and did not properly belong in the studies as they were presented. It seems appropriate, therefore, to present these data and certain impressions of the fishery at this time.

It was coincidental that the period of the study (1948–1955) paralleled a period of stress in the industry and perhaps inevitable that the commercial aspects should be recorded along with the scientific data. At no time was the design of the study geared to cure alleged ills but it did seem useful to record data pertinent to that situation, in the hope that it might prove useful to those concerned with the industry generally.

Throughout the study period, fluctuations in annual production were noted (Fig. 1). This phenomenon is common to fisheries generally, and is usually accepted as an obscure but natural course of events. Fishermen, however, generally interpreted the fluctuations as evidence of "over-fishing" and were sincere in their beliefs that the stocks of whitefish were seriously depleted. It was assumed that the basis for this belief stemmed from the memory of the extraordinary catches in 1940–42 (3) which fishermen tended to regard as normal, and from accounts of the wonderful abundance of whitefish in the early days of the fishery.

The history of the fishery reveals a succession of alarms, beginning in 1890. Prince (4) noted "In reviewing the reports and records of the Manitoba fisheries for over 30 years the [Commission] has been struck by the continual recurrence of the complaint that the Lake Winnipeg and Manitoba waters were being over-fished, and that the total depletion of the fisheries was threatened". Upon
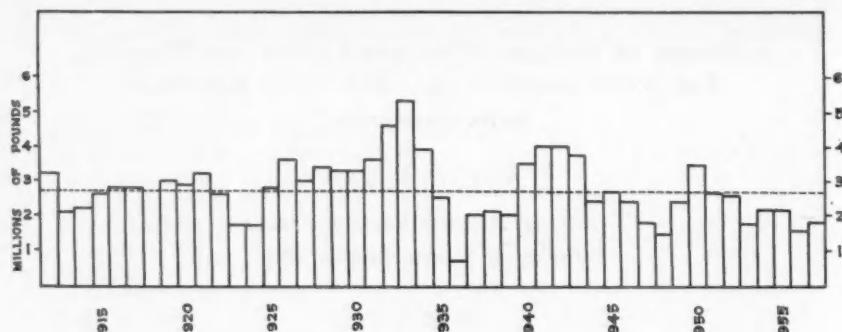

Fig. 1. Annual production of whitefish from the Lake Winnipeg fishery 1912–1957. The broken line indicates the average for the period. Figures are based on Manitoba Government records.

subsequent investigation, they concluded "but that, in spite of the excessive fishing, or over-fishing, as has been alleged, the supply of whitefish in Lake Winnipeg is still enormous, and gives no sufficient grounds for serious fear as to the future". The basis for alarm appears to stem from the realization that increases in the amount of gear fished have failed to increase the catch proportionately, in the manner that two men can harvest a field twice as fast as one. It is probable that catch increases following increases in the number of nets in the lake behave much like the subjective effect of increasing the number of the lights in a chandelier. The first candle makes an enormous difference but the tenth candle is hardly noticeable. Even so, however unjustified the past alarms, the possiblity of overexploitation is still real and deserves careful study.

The existence of Lake Winnipeg was known to Pierre Radisson and historians speculate that he may have discovered it as early as 1660. Morton (5) credits Pierre de la Vérendrye, son of the explorer, for its discovery by way of the Winnipeg River in 1734. It remained for Lord Selkirk of the Hudson Bay Company to attempt a colony in 1811 along the Red and Assiniboine rivers to the south of the great lake. His purpose was to foster a farming community to provide for the men of the fur brigades.

The new community developed too slowly to fulfil this aim, but by 1875 the city of Winnipeg had grown to 5000 people and the first Icelandic settlers had reached the shores of Lake Winnipeg. Fishing was their heritage and shipments of whitefish, *Coregonus clupeaformis*, and yellow walleye, *Stizostedion vitreum vitreum*, reached Winnipeg aboard the new steam schooners engaged in the lumber trade (6).

Old records (7) indicate a production of about 300,000 lb of whitefish annually in the vicinity of Fort Alexander and it is assumed that most of these were consumed locally. It was the custom of the Red River farmers about 1850 to visit Grand Marais late in the fall to lay up a supply of whitefish (8) and much of the annual production was probably taken during the spawning run. Evidence

supporting this assumption lies in the fact that in 1872 a commercial enterprise to supply the city of Winnipeg throughout the summer months located their fishing station at Dauphin River (9) presumably because of the unproductive nature of the southern grounds at this time of year. The venture was unsuccessful; commercial fishing was not sustained until 1883 when the pioneer firm of Reid and Clarke, using 2 sailboats, marketed nearly 73,000 lb of whitefish in the city of Winnipeg (Table I). The following year a steam powered vessel was added to the fleet, and a market was established in the United States. By 1885 exports of whitefish alone totalled more than 750,000 lb. These fish were marketed both salted and fresh, and in the winter, fresh frozen. More companies appeared and by 1887 there were 65 sailboats and 5 steam tugs employed. At

TABLE I. History of the annual production of Lake Winnipeg whitefish and of the regulations applied to the summer whitefish fishery. Production figures are in pounds dressed weight and apply to the "fishing year," i.e., from April of the calendar year shown to March of the following calendar year.

Fishing year	Production	Regulations applied to summer whitefish fishery and its development. Regulations continued effective until change noted
	lb	
1883	72,867	2 sailboats
1884	359,000	First steam tug
1885	759,730	Pound-nets tried
1886	800,000	
1887	1,400,000	7 tugs, 65 sailboats; first licences
1888	. . .	
1889	2,250,000	Season closed October 20
1890	3,400,000	25 boats, 3 tugs
1891	2,886,515	
1892	3,766,598	Sunday closure; number of nets per boat limited; fishing north end only
1893	3,810,955	13 tugs, 30 sailboats; 134,700 yards of nets; 140 men
1894	2,833,483	Season closed October 5
1895	3,665,539	
1896	3,670,820	
1897	2,754,563	
1898	2,537,401	
1899	1,996,520	
1900	3,895,100	
1901	5,000,000	
1902	6,000,000	
1903	7,000,000	
1904	7,500,000	
1905	6,500,000	
1906	5,000,000	
1907	2,000,000	
1908	2,250,000	
1909	3,468,100	
1910	2,917,500	Summer limit 2,400,000 lb
1911	3,123,300	Season June 1 to August 15; summer limit 2,500,000 lb; mesh 5½ inches

Fishing year	Production	Regulations applied to summer whitefish fishery and its development. Regulations continued effective until change noted
	lb	
1912	3,197,500	
1913	2,141,600	
1914	2,247,000	
1915	2,645,300	
1916	2,777,600	
1917	2,815,100	3000 yards per sailboat
1918	. . .	Limit 3,000,000 lb as a "War Measure"
1919	2,975,500	Mesh size 5¼ inches
1920	2,893,000	
1921	3,163,100	
1922	2,550,200	Summer limit 3,000,000 lb
1923	1,658,100	
1924	1,682,700	
1925	2,763,200	
1926	3,569,600	
1927	3,003,400	Gasoline boats replacing sailboats
1928	3,430,000	
1929	3,338,500	
1930	3,326,400	
1931	3,604,300	
1932	4,638,000	
1933	5,330,100	Summer limit 4,000,000 lb
1934	3,918,400	Summer limit 3,000,000 lb; sailboats replaced; steam tugs prohibited from fishing
1935	2,513,100	Season second Monday in June to first Saturday in August
1936	668,400	
1937	2,049,200	Summer limit 2,000,000 lb
1938	2,099,100	
1939	2,029,200	Season July 3 to August 12; summer limit 1,700,000 lb; limit on each boat
1940	3,501,500	Season third Monday in June to first Saturday in August; summer limit 2,600,000 lb
1941	4,012,000	Season second Monday in June to first Saturday in August; summer limit 2,856,000 lb
1942	4,137,600	Summer limit 3,000,000 lb
1943	3,738,000	
1944	2,356,800	
1945	2,721,200	Season first Monday in June to last Saturday in July
1946	2,420,900	
1947	1,797,100	Season second Monday in June to last Saturday in July
1948	1,531,900	
1949	2,419,300	Season first Monday in June to last Saturday in July
1950	3,531,500	Season second Monday in June to first Saturday in August
1951	2,742,300	Season first Monday in June to first Saturday in August
1952	2,572,100	
1953	1,844,900	Sunday closure rescinded
1954	2,157,400	Season first Monday in June to second Saturday in August
1955	2,177,800	Season May 30 to August 6; 5-inch mesh
1956	1,649,900	Season June 1 to August 9
1957	1,849,300	Summer limit 2,000,000 lb; individual limit removed
1958	1,616,300	

least 2 large barges were in operation, upon which were installed ice–salt refrigerating equipment. These were used to transport the accumulated catches at the fishing stations where the fish were stored frozen or salted. Whitefish catches in 1887 are estimated at nearly 1½ million lb.

By 1890, as indicated by the reports of the fishery guardians (10), whitefish were taken in quantity at several stations. Fishing at Berens Island and Reindeer Island was considered satisfactory, but catches were light toward the close of the season at Dauphin River. Winter catches too were light in these areas. The Selkirk Island station prior to 1890 was used only during the hot summer weather, presumably when catches were poor elsewhere, but in 1890 a fish company using 4 sailboats and 10,000 yards[1] of nets remained all season. They caught nearly 199,000 lb of whitefish. It is perhaps significant that a number of boats from Berens River transferred their operations to Grand Rapids for the latter part of the season. It appears that then, as in modern times, fishing at Berens River was good only at the beginning of the season.

Whitefish were taken in the more southerly regions as well, mainly from Black Island as far north as the Narrows, but in smaller quantities. A boat of 5 tons with a four man crew took 12,000 lb of whitefish during the summer season of 1890. Considerable quantities were taken by the Icelandic settlers in the winter fishery, and the production of whitefish south of the Narrows to the Red River for the year is estimated at about 62,000 lb.

The rapid increase in the production of whitefish during these years gave rise to fears of overexploitation. As a result, fishing regulations became more stringent, and open seasons were shortened. In 1892 commercial whitefish operations were confined by statute to the northern part of the lake. Gill nets allowed to each commercial company were reduced by one-half to a maximum of 20,000 yards. Whether this amounted to an actual decrease in the yardage fished by each company is not known. It would however, limit the number of sail boats employed by any company to less than 20, since each boat habitually fished 1200 to 1500 yards of nets a day. In addition fishing was prohibited from Saturday evening until Monday morning. In spite of the new regulations, production remained at about the same level, an estimated 3.7 million lb.

By 1893 the well established industry employed about 140 fishermen. They fished nearly 135,000 yards of nets from a total of 13 steam tugs and 30 sailboats, an average of about 3,000 yards per vessel. The value of boats and gear alone was estimated at about $190,000; in terms of present (1958) dollar values, about $500,000.

Commercial fishing gear has been confined to gill nets. Pound nets were tried unsuccessfully in 1885 and were not used again for whitefish. They were, however, used as late as 1890 in Pigeon Bay for sturgeon. The gill nets used in 1890 were of linen twine, the majority of them 16 meshes deep, but some 24 mesh nets were noted. The minimum legal mesh size at the time was 5 inches

[1]Metric equivalent of units commonly used in this paper are: 1 inch = 2.54 cm; 1 foot = 30.5 cm; 1 yard = 0.914 m; 1 mile = 1.609 km; 1 mile² = 2.59 km²; 1 lb = 454 g; 1 ton = 0.907 metric ton.

(stretched measure) but most fishermen preferred 5½-inch mesh, presumably because they captured fish of a larger average size.

Since that time, more efficient nets have come into use. By 1910, mesh depth had increased to about 24, and the No. 40 linen twine was almost universal. Cotton twine was introduced during 1914-1918 when a shortage of linen developed. By 1948 practically all nets were cotton of 56/6 thread or finer, and mesh depth had increased from 30 to 40. Since 1948 cotton nets have disappeared entirely, having been replaced by nylon nets of exceeding fineness. In 1911 the use of 5½-inch mesh was decreed and the regulation remained in force until 1919 when it was, by popular demand, reduced to 5¼ inches. On the basis of a scientific study, a further reduction to 5-inch mesh occurred in 1955.

Barbour (11) describes the S.S. *Manitou*, a Lake Winnipegosis freighter that was fairly typical of those used in the fisheries during these early times. She was 100 feet in length with a beam of 18 feet, and was considerably shallower drafted than the majority. She was fitted with twin screws. Her wood-fired boilers powered fore and aft compound Doty engines and she cruised at 8 to 9 miles per hour. The hold had sufficient capacity for 300 boxes of fish, each containing 150 lb net, and 150 boxes could be accommodated on deck. This vessel was built in Manitoba, launched in 1900, and remained in service for the next 42 years. The stem and stern were of oak, the keel of beech wood. The frames and planking below the water line were of rock elm. These various woods are not native to Manitoba, and were imported from Ontario. The remainder of the planking was of local tamarac. It was renewed in 1918, but the hardwoods were still serviceable at that time.

Such vessels as these were, and have remained, the work horses of the industry (Fig. 2). In the spring their holds were loaded with food supplies for the camp kitchens, nets and other gear, commissary supplies and spare parts. On the return trips to the rail head they towed the refrigerator barges laden with the frozen fish, and kept up a shuttle service throughout the summer. About 1895 the present market for fresh whitefish developed, and the freighting vessels began to transport the iced catches in their holds. The advent of Diesel power about 1930 eliminated the hot boiler room of the old steam powered vessels, providing more hold space and faciliated refrigeration of them; but in fact refrigeration facilities were little used.

The sailboats, from which most of the fishing was done, were sharp sterned keel-type boats fitted with two masts and a centre board, and steered with a tiller (Fig. 3). They were about 32 feet long but could be maneuvered with oars on the fishing grounds. These craft were difficult to handle in all but fair winds and were largely dependent on small steam tugs to tow them to and from the fishing grounds. Considerable dexterity was required of each sailboat crew as they were taken in tow one by one, in line astern, for the return trip home.

The steam tugs, varying from 10 to 25 tons, after leaving their charges in the

FIG. 2.   The Armstrong Gimli Fisheries Ltd. freighter, 1956.   Originally steam powered, her present 2-cycle diesel engine was installed in 1931.   She plies between Warrens Landing and Selkirk and cruises at about 10 miles per hour.

FIG. 3.   The two-masted sharp-sterned fishing vessels used in the whitefish fishery until about 1927.   This fleet is shown at Warrens Landing, Lake Winnipeg, August 1st, 1920.

vicinity of their nets, were themselves engaged in lifting gill nets throughout the day.   Their greater size, superior range and maneuverability contributed to their greater efficiency.

The passing years brought other changes.   About 1927 masts and sails were discarded and gasoline engines were installed in many of the old sailboat hulls. As the hulls were retired, they were replaced by larger boats 40 to 45 feet long by 10 to 12 feet in the beam.   These locally designed and manufactured boats had wide flaring bows, "square" sterns, and round bottoms (Fig. 4).   The stem

FIG. 4.   Whitefish boats in Gimli harbour, June, 1956.   The boats have loaded net trays and net buoys (to mark the net-set) and are preparing to leave for the whitefish grounds.

and keel were usually of Douglas fir, while the ribs were made of white oak.   A few were planked with cypress, but the majority were planked with the cheaper native white spruce.   The superstructure on these boats has been limited to a rudimentary shelter situated a little aft of amidships, in the form of a little deck house.   It is open at the rear and provides but limited shelter to the wheelsman and crew.   The working space, on the forward and after decks, is left open.   A flush-type hatchway in the forward deck, provides access to a fish hold about $3\frac{1}{2}$ feet in depth.   Nets and other gear are carried on the open decks.

Most of the earlier boats were powered by used automobile engines.   Most suitable were the larger 6- or 8-cylinder models which permitted speeds up to 11 miles per hour.   The industry was slow in adopting the more efficient but more

expensive marine-type motors, and makeshift engines were still common in 1948. Diesel-powered fishing boats numbered two in 1958.

A factor contributing to the slow evolution of better craft is the short season (June to August) in which they can be used. In the past, whitefish boats have been prohibited in the fall fishery (September to November) to lessen competition with fishermen who used only skiffs.

Whereas the sailboats were manned by a crew of three, the larger more maneuverable power boats could accommodate a fourth crewman, and were capable of handling more gear. By 1948 these crews were fishing 5,000–10,000 yards of gill nets a day. Very few boats had, by this time, been equipped with power net lifters. Ten years later an estimated 40% were so equipped.

In spite of the new freedom from the parent tug boat, the fishing boats tended to fish the traditional grounds in the vicinity of their home ports, that is, from 1 to 15 miles offshore. Several reasons for the practice are apparent. The fishing boats themselves are not designed for long range. The lack of adequate shelter from wind and water while travelling or lifting nets is a deterrent factor, and the absence of suitable cooking and sleeping facilities is another. Many of the ports cannot be safely navigated in the dark. Suitable anchorages are few and harbours fewer. The gasoline powered engines are relatively expensive to operate, and many of the aging wooden hulls are unsafe in heavy seas. Most fishermen are committed to deliver their catch to one packer, and daily runs to their home ports are therefore necessary.

Due to the short range of the fishing boats, shore facilities in the form of ice houses, kitchens and bunk houses, sheds and docks have been built at almost every anchorage or harbour adjacent to the favoured fishing grounds. The earliest of these, as already mentioned, were built mainly along the west shore (see map, Fig. 5). Fishing at Warrens Landing, Mukutawa River and Berens River was established a little later, probably within 2 or 3 years. As time went on, fishing stations became numerous along the east shore, especially from Poplar Point to Warrens Landing. Counting those at George Island, they numbered about 18 in 1950.

This notable concentration of fishing stations along the east shore readily creates the impression that fishing is very much better there. Without going into this proposition, it is well to examine other reasons. The physical features of the western shoreline restricted the available harbours there to those already mentioned and, of these, Dauphin River, Grand Rapids and Limestone Bay were closed to the whitefish fishery in 1911 as a conservation measure. This left only the Selkirk Island station operating on the west shore. It too was vacated in 1948 for some years and the boats moved to Mukutawa River.

The relative productivity of the west shore is difficult to assess for the reason that so few boats were based there. The boats can, and do, fish the grounds, but only as long as lifts are large enough to warrant the extra cost of reaching them from distant ports (12). The productivity of the grounds is further attested to by a successful annual winter fishery in the Grand Rapids

FIG. 5. Lake Winnipeg showing fishing ports. The Roman numerals designate stations at which whitefish were sampled for study.

region, and remotely, by the fact that in 1894 and 1895 most of the effort for the summer was expended in the vicinity of Selkirk and Pony Island (13). The prevalence of rough fish, mainly suckers (*Catostomidae*) and burbot (*Lota lota*), as well as the comparative scarcity of shoal water, contribute to the unpopularity of the west shore to some degree.

THE MIGRATION TO THE EAST SHORE

During the course of the biological investigations mentioned earlier, the investigators noted a gradual increase in the number of boats based along the east shore, and a corresponding decrease at other ports. From 1944 the number of boats based in the region increased from 45% of the total fleet to 49% in 1948–51 and, still further, to 65% in 1952–54.

The clue to the migration of the boats to the east shore lies in basic economic factors associated with costs of production and the price that the product brings. Together with some other primary industries, during the past few years prices have failed to keep pace with rapidly rising operating costs. The effects were cushioned at first by a series of better than average yields from 1940 to 1943 (Fig. 1), whereas subsequent yields have tended to be less than average, and distress in the industry became acute. The packers reacted to the situation by closing some marginal stations altogether, and shifted the boats to other stations. The closing of these stations was interpreted by many as resulting from "over-fishing".

At this point it might have been desirable to eliminate the more inefficient fishermen so that the available fish could be divided among fewer boats, thereby decreasing unit costs, or to improve the efficiency of the boats for the same end. A fundamental characteristic of the industry, however, prevented prompt effective action.

Available licenses were limited to 150, and licensees were protected by their seniority. Thus, 150 particular license holders pressed to be accommodated at one station or another. Because of the almost complete dependence of the fishermen upon the packer for a boat, about one-third of his gear, and advance financial aid even in good times, the fisherman's only real bargaining point was his license. Another, anomalously, was the fact that he was chronically in debt to the packer, and deserved a chance to repay his debt.

Under favourable economic conditions this system, which somewhat resembles medieval serfdom, operates to the advantage of the packer. Keeping his fishermen more or less indentured, he was not obliged to bid for their services, nor did he need to compete with other packers for their product. The packer balanced receipts and expenditures at the end of the season, took the profit he felt was justly his, and divided the remainder among the fishermen. Those fishermen who fail to balance their costs are therefore carried by those whose better luck or skill goes unrewarded.

Under unfavourable economic conditions, however, the system operates to the disadvantage of the packer. As the fishermen's banker, some of his capital

is being used for desultory purposes when he may need it to install diesel engines in his boats.   Indeed, at such a time it might be an advantage to obtain boats by contract, so that he could employ only as many as he needed.   But the packer owns the boats, and idle boats mean idle capital.   The incentive, therefore, is strong to operate his full complement in an attempt to hedge his investment.

Inevitably, and after prolonged hardship, a reduction from 149 boats in 1952 to 85 in 1958 did occur.   Many of the better fishermen abandoned the fishery entirely, and moved to Great Slave Lake.   This left the Lake Winnipeg fishery staffed with a greater than usual proportion of less successful fishermen.

The nature of the reorientation of the fishing boats is shown in Table II. The bulk of the displaced fishermen were formerly (1940–1947) based at Cannibal, Little George, and George Island who, presumably, fished to the southwest, or in competition with other boats along the southeastern shore.   When decreased catches or increased operating costs (or both) made this region unprofitable, the move was necessarily to the northeast shore where suitable facilities existed, and where fishing was presumed to be much better.

Annual production did not improve, and it can be assumed that over-all efficiency was decreased by increased competition of the gear in this area.   Many fishermen insisted that the lake was "fished out".   They tended to fish closer to their home bases than formerly, because they felt that they couldn't risk time and gasoline in exploration.   Many increased the amount of gear, and of necessity, it was set closer to their home ports to save valuable time.

From these data, it can be concluded that about two-thirds of the fishing effort for whitefish is expended in a strip of water within 12 miles of the shore from just south of Poplar Point to just northwest of Warrens Landing.   This constitutes about 750 square miles out of a total of about 6300 square miles in the whitefish area as whole.   There are about 3000 square miles around the perimeter of the lake within 12 miles of the shore, exclusive of the areas closed to the whitefish fishermen.   There are indications (Hewson, 1959) that fishing there is comparable to that within the 750 square miles where it is now concentrated. Since two-thirds of the fishing is concentrated in one-quarter of the peripheral area, and assuming that approximately half of the remainder (that based on George and Sandy Islands) is done in the centre of the lake, then a simple calculation shows that the 1954 fishing effort per square mile, in these 750 square miles, was roughly 12 times as great as on the remainder of the whitefish grounds within 12 miles of the shore.

RECENT DEVELOPMENTS

By 1954, the whitefish license, once a valued privilege, was no longer considered as such by many fishermen.   The former relationship between packer and fisherman had changed to the extent that fishermen became employees of the packing company at a fixed wage.   As an incentive, a bonus was offered on production above a certain amount.   It is reported that although most fishermen

TABLE II. The number of boats licensed to fish for whitefish at each fishing port on the northern end of Lake Winnipeg during 1940 to 1954.

	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Selkirk Island	...	...	...	...	...	...	...	...	6	5	...	...	...	...	8
Warrens Landing	7	7	17	16	17	17	17	17	25	22	25	25	25	27	24
Montreal Point	...	...	...	...	...	...	...	...	8	8	8	8	8	7	8
Spider Island	18	8	14	14	14	15	14	20	21	13	14	22	22	22	21
Birch Island	7	8	8	8	8	8	8	8	8	7	8	8	8	8	8
Shoal Point	5	5	7	7	7	15	15	15	7	7	7	7	7	6	7
Mukutawa River	28	28	29	25	25	25	25	25	29	24	25	25	25	22	14
Poplar Point	15	14	17	14	11	12	13	13	16	13	13	13	13	12	11
George Island	25	41	34	35	37	37	37	26	18	21	31	20	19	12	13
Little George Is.	7	8	8	8	8	...	...	...	...	...	...	...	...	...	...
Cannibal Island	...	9	8	8	8	7	6	10	8	7	8	8	8	...	...
Sandy Island	6	8	7	7	8	8	8	8	8	7	8	8	8	5	6
Berens River	...	...	1	8	7	7	7	8	4	6	11	14	14	11	11
	118	136	150	150	150	151	150	150	150	133	150	150	149	132	131

were working for wages, a small number of the more astute and skillful fishermen during 1958 negotiated contracts and fished at their own financial risk, and enjoyed considerable success.

An index of fishing success (Table III) indicates varying success since 1953 with no trend toward better or worse fishing. The index for 1955 shows an

TABLE III. Index of fishing success for Lake Winnipeg summer white-fish licensees, based on season average catch per boat in pounds divided by 1000.

Year	No. of licensees	Index
1953	150	8.0
1954	131	9.9
1955	130	12.3
1956	126	7.9
1957	98	13.2
1958	85	9.4

improvement over the previous year which may have been due to a reported increase in the illegal use of $4\frac{1}{4}$-inch mesh nets on the whitefish grounds together with the advent of the smaller legal mesh of 5 inches.

The catch limit imposed on individual licensees in 1939 was rescinded in 1957. It is doubtful if the action had any appreciable impact, but theoretically at least, it offers encouragement and is some inducement for efficient fishermen to enter the fishery. In 1958, at least one fishermen exceeded the limit set by the former statute.

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Maturity and Breeding of the Pacific Edible Crab, *Cancer magister* Dana[1]

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ABSTRACT

The breeding procedure of *C. magister* is described. Contact between the male and female in the pre-mating embrace causes marks on the exoskeletons. These "mating marks" are used as an indicator of breeding activity of male crabs. Differences in intensity of mating marks are discerned, and these are interpreted as evidence of polygamy under natural conditions.

Examination of vasa deferentia and sampling of male breeding crabs has indicated that onset of maturity in the Queen Charlotte Islands occurs at a carapace width of about 110 mm, or at approximately three years of age. However, sexual activity is not appreciable until the width is about 140 mm.

Female crabs are mature at a carapace width of 100 mm, at about two years.

INTRODUCTION

MUCH IS KNOWN about reproduction of the Pacific edible crab *C. magister* Dana, based upon investigations conducted in southern British Columbia and the State of Washington. Fasten (1915) described the male reproductive organs and later (1918) the spermatogenesis of the species. Spencer (1932) described mating procedure and changes in gonads of both sexes during the breeding season. From a study of proportional measurements, examination of reproductive organs and observations of mating pairs, Weymouth and MacKay (1936) concluded that the female *C. magister* is sexually mature at a carapace width of about 100 mm. Later MacKay (1942) found, from examination of gonads, that the male crab was mature at a carapace width of 5.4 inches (about 137 mm). In 1949 Cleaver stated that male crabs were able to breed before reaching the size of 169 mm[2]. In the same paper, Cleaver described the polygamous behaviour of male *C. magister* in aquaria, and assumed that it occurred also under natural conditions.

Since 1947 the Fisheries Research Board of Canada has conducted an investigation of the major crab fishery of British Columbia, located adjacent to the northern Queen Charlotte Islands. The objectives of the present study were to determine the size at which male and female crabs become mature in northern

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British Columbia; the size composition of breeding males; and whether males are polygamous in their natural habitat.

The Queen Charlotte Island fishery, like other regions in the province, depends almost on male crabs, because females seldom attain the minimum size limit of 165 mm (6½ in).

SIZE OF *C. MAGISTER* AT MATURITY

Sections of vas deferens and smears of seminal fluid were collected from 10 male crabs with carapace widths from 116 to 177 mm. A 1-cm portion of vas deferens was removed from each crab in the field and fixed in Bouin's solution. Later this tissue was sectioned and stained with Heidenhain's iron-hematoxylin. Smears of seminal fluid were similarly fixed and stained.

All vasa deferentia examined contained spermatophores with mature spermatozoa, indicating sexual maturity. Figure 1 is a photomicrograph of a section of vas deferens from a crab with a carapace width of 116 mm. The dark-stained bodies are spermatozoa contained in the circular capsular spermatophores. In this section the wall of the duct is not intact. The presence of fully developed spermatozoa showed this crab had attained sexual maturity. The age of this male is estimated at about two years. Other males of 119, 122, 132, 137, 141, 157, and 164 mm in carapace width, all under the minimum size limit, were mature.

BREEDING PROCEDURE OF *C. MAGISTER*

The breeding of *C. magister* has been observed in aquaria by Cleaver (1949) and by the writer but, as far as known, never under natural conditions. Copulation takes place between a hard-shelled and a soft-shelled (recently moulted) female. What is usually observed is an embrace prior to the ecdysus of the female. The male finds a hard-shelled female and holds her until she moults. In this "pre-mating embrace" the male clasps the female with his chelae so that the sterna of both are in contact.

It is not certain whether the male continues to hold the female throughout her ecdysis. Soon after the shell of the female is cast, copulation occurs. During this act the female rests on the dorsal surface of her carapace with the male directly over her. The abdomens of both are flexed, permitting the paired copulatory organs to be inserted into the sternal apertures of the female. Apparently the spermatophores rupture after leaving the vas deferens during copulation for only free spermatozoa are found in the spermathecae or evaginations of the oviducts. Copulation is possible only while the female is soft-shelled.

In the Queen Charlotte Islands region breeding generally occurs from May to September. Spermatozoa remain viable in the spermathecae until the ova mature in autumn, several months later. After fertilization, which occurs in the oviduct, the ova are extruded and become attached to setae of the endopodites of the pleopods.
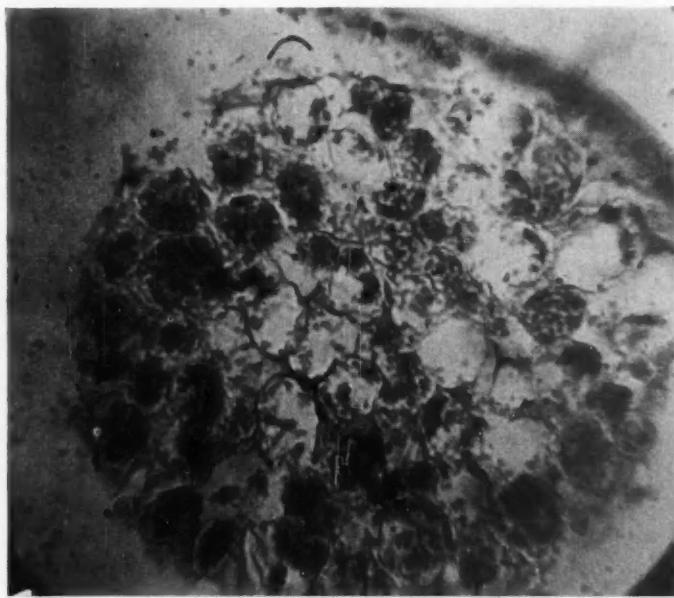
FIG. 1. Photomicrograph of section of vas deferens of male crab, carapace width 116 mm (800×).
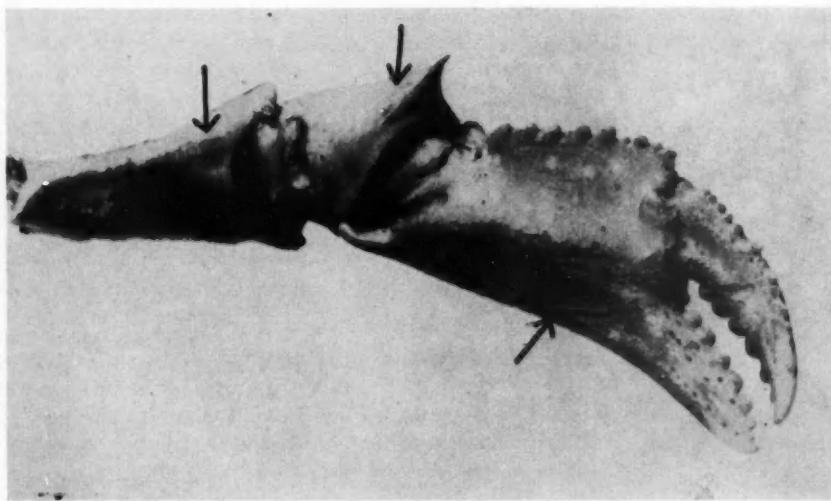

FIG. 2. Photograph of cheliped of male *C. magister*, showing "mating marks" which are indicated by arrows.
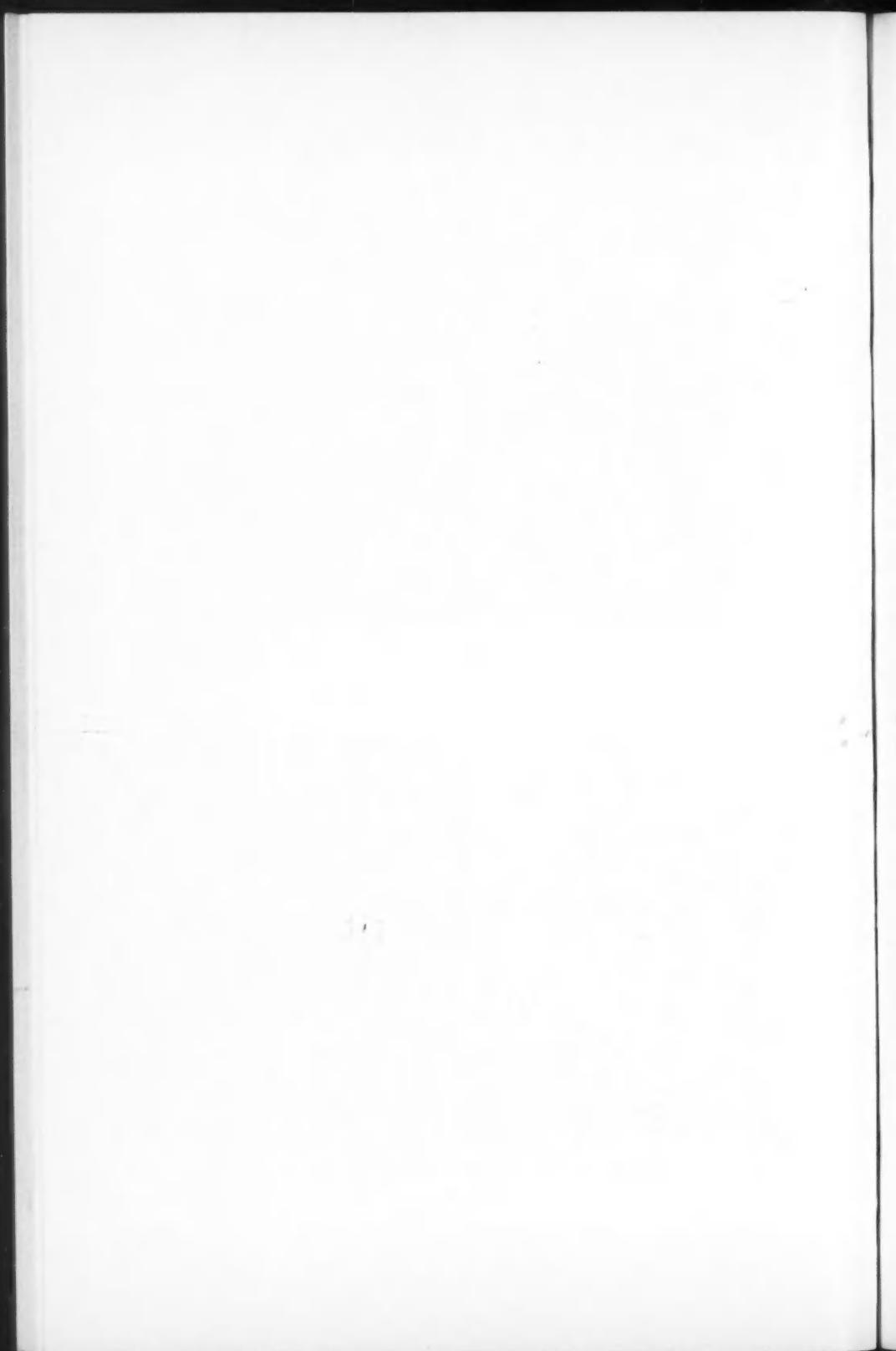
SIZE OF CRABS IN THE PRE-MATING EMBRACE

Although males smaller than the minimum size limit were sexually mature, it was not certain whether they participated actively in breeding. In the years from 1949 to 1957, measurements were made of 128 mating males and 91 females collected in the intertidal zone and from crab traps. Carapace widths of males ranged from 141 to 212 mm; and of females from 78 to 171 mm. Fifty-two males were less than the minimum size limit; and 13 females had carapace widths of 100 mm or less.

This relatively small sample of mating males indicates that individuals of sub-legal size form an important part of the male breeding population. Mating females of 100 mm and smaller are mature, as found by Weymouth and MacKay (1936) in southern British Columbia. Cleaver (1949) reports that the smallest mature female was less than 80 mm (72 mm, shoulder width).

MARKS ON THE EXOSKELETON OF *C. MAGISTER*
CAUSED BY THE PRE-MATING EMBRACE

Mating pairs are not always available from the intertidal zone and the procedure of fishing generally separates pairs which enter crab traps, but it is now possible to obtain large samples of males known to be breeding.

Close contact during the pre-mating embrace produces marks or an abrasion at several places on the exoskeletons of both male and female crabs. The marks are such as might be made by a grinding wheel. In male crabs the marks occur on inner surfaces of the manus, carpus, and merus of the cheliped, as shown in Fig. 2, with the most conspicuous and common ones on the manus. Conspicuous abrasion on the female exoskeleton appears along the antero-lateral margin, where the 10th, 9th, and 8th spines become quite blunt. Mating individuals of both sexes have less obvious worn spots on the fused anterior sterna.

Search for "mating marks" was made on unaccompanied male crabs during the summers of 1953 and 1954 in Hecate Strait, McIntyre Bay and Naden Harbour. Of 5461 male crabs examined, 1540 had mating marks; carapace widths were from 107 to 218 mm. Occurrence of mating marks on legal-sized and sub-legal-sized males was as follows:

Mating marks	Legal size	Sub-legal-size
Present	1224	316
Absent	3637	284

Thus the relative breeding activity of sub-legal-sized males was slightly more than twice that of the legal-sized crabs.

Included in the above total is a sample of 1920 males collected from commercial crab traps in Hecate Strait on July 24 and 28, 1954. In this sample, distribution of mating marks according to size was as follows:

Mating marks	Legal size	Sub-legal-size
Present	552	113
Absent	1210	45

Carapace width frequency distributions of the total Hecate Strait sample and of males with mating marks are shown in Fig. 3. The smallest male examined was 119 mm but no individual less than 138 mm was found with mating marks. There is relatively small representation of males of 180 mm and larger in the mating group. At the time of sampling most of the large males had moulted recently, and very few of these had mating marks. It is likely that the greater part of the soft-shelled males had mated prior to moulting, and perhaps would have mated again before the end of the breeding season.
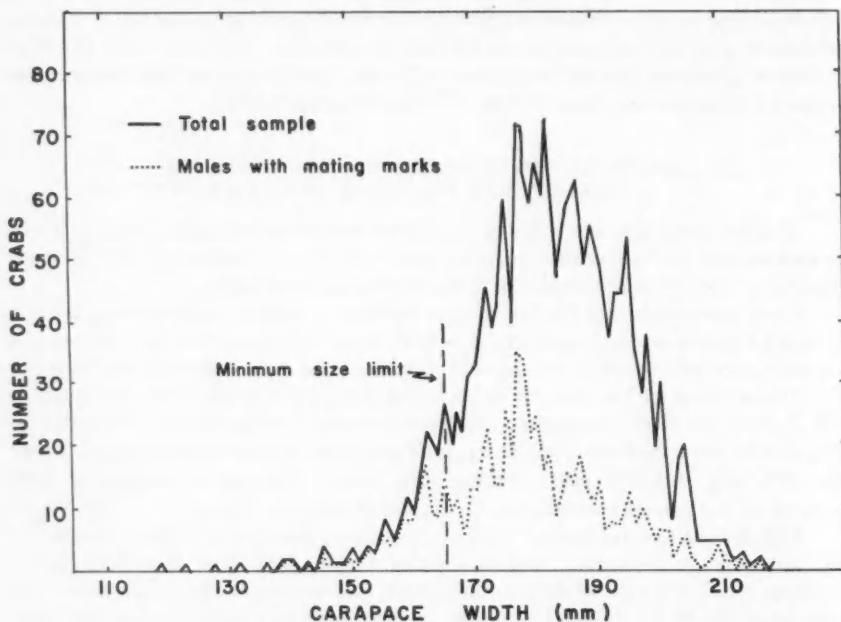

Fig. 3. Carapace width frequency distribution of male *C. magister*, from Hecate Strait July 24 and 28, 1954.

Close examination of mating marks on male crabs revealed differences in the degree of abrasion. Marks varied from a few sharp scratches to wide deeply worn bands. Since mating marks are caused by close contact in the pre-mating embrace presumably the amount of wear would be related directly to the period spent in embrace. No obvious differences have been found in the character of the female mating marks which would indicate that the period spent in embrace by this sex varies greatly. It seems likely that heavy male mating marks are caused by a prolonged pre-mating embrace not with one female alone but with several females.

DISCUSSION

The present histological study has shown that male *C. magister* having carapace widths of 116 mm and larger are sexually mature. The smallest male actually observed in pre-mating embrace was 141 mm, and the smallest male with mating marks measured 107 mm. Cleaver (1949) records a male of 112 mm (106-mm shoulder width) in embrace. It is quite likely that sexual maturity is reached at about 110 mm by some individuals. However, the sizes of males in embrace and of those with mating marks indicate that an important degree of breeding activity begins at about 140 mm, when the crab is believed to be three years old. Presumably most male crabs will breed before reaching the minimum size limit of 165 mm.

With female crabs the assumption that maturity is reached at a carapace width of 100 mm or less is based upon observations of individuals found in pre-mating embrace. Functional maturity, i.e., the spawning of fertilized eggs, does not occur until after ecdysis. Females of 80 to 100 mm increase about 24 mm at ecdysis, so mating individuals in the present sample could be expected to be 100 mm or larger by spawning time. Therefore it is likely that in the Queen Charlotte Islands maturity is attained by the time the female crab is 100 mm, at an estimated age of two years.

Marks on the exoskeleton caused by contact during the pre-mating embrace apparently have not been reported previously. I have seen no mention of their occurrence on the European edible crab *Cancer pagurus*. No marks were found on two other Pacific species, *C. productus* and *C. gracilis*, examined by the writer.

Direct proof of polygamous behaviour under natural conditions is practically unobtainable. The present observation of variations in amount of abrasion on mating marks is taken as circumstantial evidence of polygamy. Probably it is safe to conclude that polygamy exists in nature and certainly Cleaver (1949) makes the assumption on the basis of laboratory observations only. However, its importance in the reproduction of natural populations is unknown. Since only males are fished it is obvious that polygamy will be more prevalent in an exploited population than in an unfished one. Cleaver implied that the reproductive capacity of the heavily exploited stock along the Washington coast was maintained by polygamy.

Another factor which may be important by itself or in conjunction with polygamy is increased breeding activity of small males in an exploited population. Field observations have shown that two males will fight for a breeding female, and invariably the larger male is successful. One may expect in an unfished stock breeding activity of small males would be restricted by competition with a large group of legal-sized males. It is reasonable to assume that the present demonstration of relatively intense breeding of sub-legal-sized males may be related to the fact that the sample was collected from an exploited crab population. Further sampling is required to determine whether a relationship exists between the activity of sub-legal-sized males and the rate of exploitation. If so, breeding activity of undersized males may prove to be a useful index of exploitation of crab populations.

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A Mutant Pike, *Esox lucius*[1]

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ABSTRACT

A striking variant of the northern pike, *Esox lucius*, differing from the normal pike in colour and in some morphological measurements, comprised 0.2% of the pike population of Heming Lake, Manitoba.

INTRODUCTION

A STRIKING VARIATION of the northern pike, *Esox lucius*, was first noticed in Heming Lake, Manitoba, in the summer of 1952. The fish had the morphological characters of *E. lucius*, but lacked the spots and other marks (Fig. 1) and differed markedly in colour. In appearance, this fish matches the description of a pike variant reported by Eddy and Surber (1943) from several areas in Minnesota.

Since the discovery of the pike that differed so much from the normal pike, the daily catch of fish at Heming Lake has been carefully watched and many more specimens have been recorded. Some specimens might have been overlooked by student assistants, who in the early part of the season were not very familiar with the fish they were handling but, because of the conspicuousness of the animal, it is unlikely that the number missed could have been very large. Complete taxonomic measurements were made on most of the variant pike captured and a good sample of this fish has been sent to the Royal Ontario Museum, Toronto, Canada. Some attempt has been made to determine the occurrence of this type of pike in other parts of Canada. For convenience in distinguishing the unusual pike from the normal pike, it will be called "silver pike" as suggested by Eddy and Surber.

DESCRIPTION

COLOUR. The body is coloured deep blue on the back, shading through lighter blue and grey to white on the belly. The flanks might be more specifically identified as dark silver or grey, sometimes flecked with gold. The fins, particularly the ventral ones, appear tinted with orange and red and may sometimes be speckled with black. The opercle is scaled on the upper half only and the cheek is entirely scaled as in the normal pike. In all other respects,

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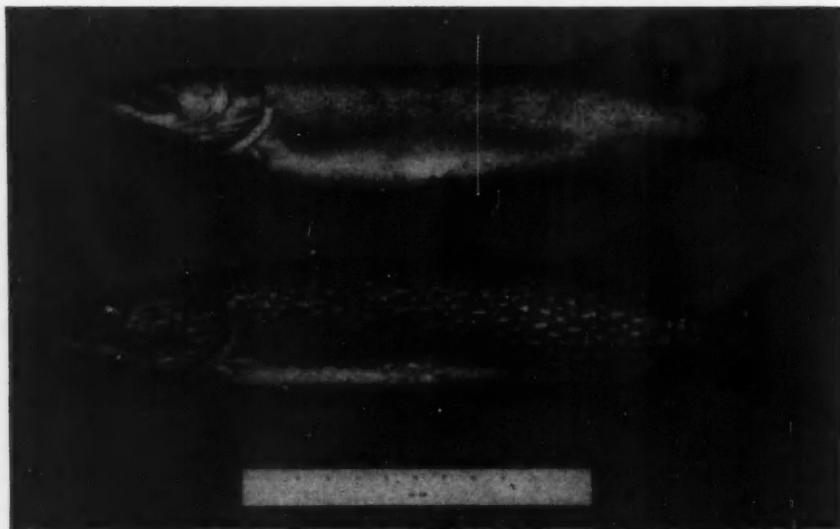
FIG. 1. Photograph of silver pike (*upper*) and normal pike (*lower*). showing distinctive colour patterns.   The rule is 12 inches (305 mm) long.

it appears to resemble the normal northern pike.   Variant pike can be readily distinguished from normal pike even after death, as the silver colour does not fade but rather becomes intensified.

FREQUENCY OF OCCURRENCE. The silver pike constitutes a very small fraction of the total pike catch (less than 1%) in any one year.   If the distribution of the

TABLE I. Number of normal pike and silver pike, and the percentage frequency of silver pike, in Heming Lake catch during the years 1952 to 1958.

Year	Normal pike	Silver pike	Percentage silver
	no.	*no.*	%
1952	1,468	4	0.28
1953	1,376	2	0.14
1954	1,394	2	0.14
1955	1,948	4	0.20
1956	2,257	5	0.22
1957	3,760	14	0.37
1958	7,175	11	0.15
Total	19,378	42	0.21

silver pike is widespread, the apparent scarcity in a population probably accounts for the fact that it has not been frequently reported.

SIZE AND AGE. The smallest fish captured was 10 inches (254 mm) fork length and weighed 5 ounces (140 g), while the largest pike taken was 25 inches long (635 mm) and weighed 4 lb, 14 oz (2210 g). Average length and weight of silver and normal pike at each age were compared. Considering the fact that the sample of silver pike was collected over a 6-year period and constitutes a relatively small sample compared with the sample of normal pike, it is worth noting that at each age the average length and weight of silver pike was greater than for normal pike.

INTERNAL ANATOMY AND SEXUAL MATURITY. The sex of each pike was determined and the viscera were examined. Although no detailed comparison was made between silver pike and normal pike, there did not appear to be any differences striking enough to distinguish them on their total visceral appearance.

There is no doubt that silver pike mature and reproduce in Heming Lake, as ripe and spent animals of both sexes were recorded. The gonads (although not histologically examined) looked exactly like the gonads of normal pike. Although few fish were taken at or near the time of spawning, it would appear that the silver pike mature and spawn at about the same age and size as the normal pike. The evidence indicates that some 3-year-old females spawn but the majority probably spawn as 4-year-old fish. The only evidence concerning the age at which males spawn was obtained from two larger fish which were exuding milt when captured in the early spring. These fish were both 5 years of age.

COMPARISON OF SOME TAXONOMIC CHARACTERS IN SILVER AND NORMAL PIKE

Taxonomic measurements followed the methods of Hubbs and Lagler (1949). Data, in graphical form, not presented in the text are on file at the Fisheries Research Board of Canada Biological Station, London, Ontario.

LATERAL LINE SCALES. A comparison of the frequency of different ranges of scale counts for 33 silver pike and 189 normal pike is shown in the accompanying schedule. Two silver pike had scale counts slightly higher than the maximum number present in the sample of normal pike.

Range	Silver Pike		Ordinary Pike	
	no.	%	no.	%
109–112	1	3.1	1	.5
113–116	4	12.1	3	1.6
117–120	7	21.2	43	22.7
121–124	8	24.2	59	31.2
125–128	8	24.2	68	36.0
129–132	3	9.1	15	8.0
133–136	2	6.1	0	0

MANDIBULAR PORES. All silver pike examined had 5 mandibular pores on each side of the mandible. The same was generally true for normal pike, except in a few instances where one or the other side of the mandible had 1 pore missing, thus giving a total count of 9. No pike was found that had 11 mandibular pores.

BRANCHIOSTEGAL RAYS. The counts of the branchiostegal rays of silver pike fell within the range of the count for the normal pike.

No. of branchiostegals	Silver pike no.	%	Ordinary pike no.	%
24	. . .	0	2	1.0
26	1	3.1	8	4.0
28	9	28.2	54	27.0
30	19	59.3	128	64.0
32	3	9.4	8	4.0

In two silver pike (6% of the sample) there was some asymmetry with 14 branchiostegals on one side of the isthmus and 15 on the other. Branchiostegal asymmetry occurred in 33% of normal pike examined.

FIN RAY COUNTS. Dorsal, ventral and anal rays were counted and in every case the silver pike fell well within the range of the ordinary pike.

HEAD LENGTH. Head lengths of silver and normal pike were plotted against standard length to see if the two groups separated naturally, but all points were closely associated over the total range of lengths and no obvious differences were noted.

BODY WIDTH. When body width was plotted against standard length, there appeared to be a natural separation of silver and normal pike in the length range 150 to 400 mm (6–16 inches) with the silver pike consistently narrower (thinner) than the normal pike. Between 400 and 550 mm (16–22 inches) the few silver pike measurements fell within the range of the more numerous normal pike measurements.

EYE DIAMETER. Although eye diameter cannot be measured as precisely as a bony structure, the data appear to indicate that the diameter of the eye of the silver pike is slightly larger than that of the normal pike.

MANDIBLE. Mandibular lengths of silver and normal pike plotted against standard length on arithmetic graph paper showed some variation. When the best straight line was fitted by eye, it was found that 23 of the 28 silver pike mandibular lengths fell below this line indicating, admittedly roughly, that the silver pike had slightly shorter mandibles than did the normal pike.

MAXILLARY. When maxillary lengths of silver and normal pike were plotted against standard length and the best straight line was drawn by eye through the points, it was found that 24 of the 26 points representing maxillary length of silver pike lay below the line. A best straight line drawn through the points for silver pike would also lie below the best straight line for normal pike, indicating that the maxillary of the silver pike is slightly shorter than that of the normal pike.

INTERORBITAL WIDTH.   The most marked morphological difference between silver and normal pike is the smaller interorbital width of the former.   When interorbital distances were plotted arithmetically against the standard length,
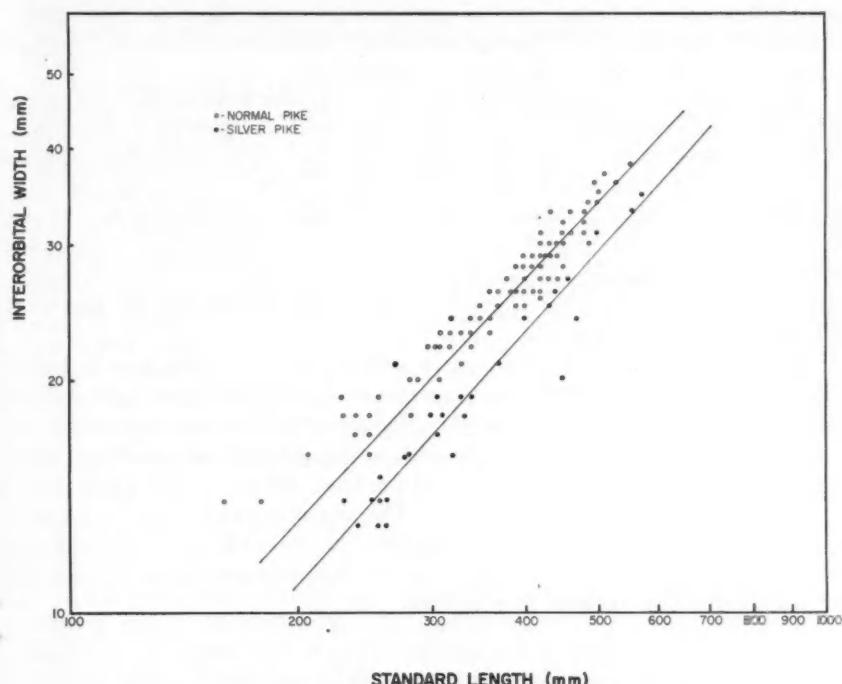

STANDARD LENGTH (mm)

FIG. 2.   Relation between interorbital width and standard length of normal and silver pike from Heming Lake, Manitoba.   Lines drawn by inspection.

it was possible to draw a line through all the points above which only normal pike occurred and below which only silver pike occurred.   When plotted on logarithmic paper, two distinct lines with approximately the same slope emerged (Fig. 2).

SUMMARY OF MORPHOLOGICAL CHARACTERS

The silver pike differs from the normal pike in some morphological characters as well as in colour.   The smaller silver pike are somewhat narrower in body width than the normal pike.   The silver pike appear to have larger eyes than the normal pike.   This conclusion, based on measurements of eye diameter, is strengthened by evidence that the interorbital width of silver pike is distinctly smaller than that of normal pike.   There is some evidence that mandible and maxillary are both shorter in the silver pike.

FEEDING HABITS AND VITALITY

Stomach contents of most silver pike captured were examined and it was found that the types of food eaten was about the same as that consumed by normal pike. Food items included perch (*Perca flavescens*), common sucker (*Castotomus commersoni*), spottail shiner (*Notropis hudsonius*), ninespine stickleback (*Pungitius pungitius*), and troutperch (*Percopsis omiscomaycus*).

Silver pike held in aquaria did not eat when first introduced. One silver pike went 22 days without food although ample food was provided. After that, it ate sporadically until it died, 47 days after capture. At death the fish appeared quite emaciated. During its life in the aquarium, the silver pike had been severely attacked by *Saprolegnia*, which was remedied twice by immersing the fish in a rather strong formaldehyde solution and rubbing the infected areas until they became red in colour, in contrast to the silver sheen of the non-infected areas. After each washing the pike appeared to be in good health and ate well until infected again with saprolegnia.

Our limited observations appear to indicate that the silver pike is hardy. In at least two instances, silver pike were taken by angling and the angler stunned the fish by holding it by the eyes while removing the lure, following which the fish was thrown to the deck of the boat with no thought of keeping it alive. After being "out of water" for upwards of 2 hours, these fish were revived and placed in aquaria with no apparent ill effects. The apparent exceptional hardiness of this fish has also been reported, by observers, to Dr W. B. Scott of the Royal Ontario Museum, Toronto. Further data of a quantitative nature are required to substantiate these general observations.

DISTRIBUTION

In Manitoba, silver pike have been found by the writer in two small lakes adjacent to Heming Lake. In one of the lakes, known locally as Anglers Lake because of the good pike fishing found there, the incidence of silver pike is higher than in Heming Lake. In 1958 two silver pike were taken in a catch of approximately 60 fish. In 1959 the same ratio applied. This lake is about half a square mile (1.3 km²) in area, does not exceed 8 feet (2.5 m) in depth and appears to have a small population of large fish. Love Lake, a very shallow lake which drains into Heming Lake, has a very small pike population as judged by angling and gill net returns, but has some silver pike. In 1958, anglers caught 8 pike, one of which was a silver pike; in 1959, two 50-yard (46-m) gill nets fished daily for 7 days yielded only 7 pike, one of which was a fine specimen of a silver pike. No other silver pike have been reported in Manitoba. One experienced commercial fisherman, on seeing a silver pike, stated that he had seen one of these about 25 years previously in Fay Lake, another relatively small shallow lake near Heming Lake, but had not seen one since then.

In 1954, a silver pike caught in Mississippi Lake, near Ottawa in eastern Ontario, was sent by Dr W. M. Sprules to Dr W. B. Scott, of the Royal Ontario Museum, for his opinion as to its taxonomic position. Further records indicate that there is an unusually high incidence of silver pike in this Ontario lake. Dr Scott has stated that he has on file a few scattered reports of its occurrence in Ontario.

A 5-pound (2.3 kg) silver pike was recorded in a catch of 150 normal pike from Beaverlodge Lake, east of Great Bear Lake, Mackenzie, in 1959 by a field party of the Arctic Unit of the Fisheries Research Board of Canada. This is the northernmost record of its occurrence in North America.

Eddy and Surber (1943) report that the silver pike was first observed in 1930 in Lake Belletaine, Minnesota, where it is quite common. Eddy (personal communication) states that he has received various reports of the appearance of pike of this nature from various lakes in northern Minnesota and Wisconsin.

The occurrence of silver-coloured pike is not confined to this continent. Runnström (1949) reported that G. Svärdson had found an abnormal silver-coloured mature pike and fertilized its spawn with milt from a 1-year-old male. Subsequent reports (Runnström, 1950, 1951) described the success of the hatching, but in a conversation with Dr Svärdson in 1958, he said that he had not had much success in keeping these fish and breeding another generation.

DISCUSSION

Eddy and Surber (1943) state that this unusual looking pike is a true-breeding mutant of *Esox lucius* that has definitely established itself in several lakes where it breeds with others of its kind rather than with the accompanying northern pike. When crossed with the northern pike, the resulting hybrids have a peculiar black mottling. Dr Samuel Eddy, in a personal communication (1959), stated that in several lakes where this mutant was planted, the recoveries have not indicated that they established a breeding population; however, in Lake Belletaine the presence of this form over a long period of time seems to indicate that it was abundant enough to establish a breeding population, as he never had any difficulty obtaining brood stocks of this fish from traps. He suspects that the introduction in other lakes could easily have been swamped by cross breeding with ordinary *E. lucius*. Because of the infrequent occurrence of silver pike in Heming Lake, it does not appear as though this mutant form is breeding with others of its own kind. Occasionally pike are captured which have some of the colour markings of the silver pike, but which are not considered to be true silver pike and these are recorded as silver × normal hybrids.

The silver pike can be reared in hatcheries as has been done in Minnesota and its addition to any pike-producing lake would certainly be an asset because of its pleasing appearance and robust nature. Its culture would also be of con-siderable benefit for short-term population studies, as the distinctive colour of the animal would serve as a natural tag.

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The Behaviour of Pacific Salmon Fry During Their Downstream Migration to Freshwater and Saltwater Nursery Areas[1,2]

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ABSTRACT

The downstream migration of sockeye, coho, pink and chum salmon fry is initially nocturnal and appears to be regulated quite precisely by changes in light intensity. Downstream movement is seen to arise from a displacement by the current when firm visual contact with fixed objects in the stream is lost. Once the migration is under way the distribution of the fry varies. The lateral distribution of pink and sockeye, but not chum and coho, was closely and positively related to current speed, above a threshold of 1.3 ft/sec (0.4 m/sec). Pink fry were found to be distributed throughout the total depth of water but greatest catches were made at intermediate depths. The negative response of fry to light appears to change after exposure to it, and pink and chum fry were found to extend their movements into and throughout the daylight hours where the migration route was lengthy. Feeding and schooling activity is probably associated with this change in response to light. Both pink and chum fry were observed to school only near the end of their seaward movement. Pink fry were found to feed to some extent in the natal areas but to a greater extent as the sea was approached.

INTRODUCTION

THE YOUNG of the Pacific salmon migrate from their natal area to a freshwater nursery area (sockeye *Oncorhynchus nerka*, coho—*O. kisutch*), or else to salt water (pink—*O. gorbuscha*, chum—*O. keta*). Considerable information on their movements is available. Neave (1955) described the migration of pink salmon fry from streams on the Queen Charlotte Islands of British Columbia. Extensive observations have been reported by Hoar (1956, 1958), Mackinnon and Hoar (1953) and Keenleyside and Hoar (1954) in a comparative study of the behaviour of young salmon in the laboratory and in controlled field situations.

Generally the migration of fry appears to be governed to a considerable extent by their response to light and current. In the above studies the migration of pink fry was found to take place over a period of weeks in the spring, and was shown to be primarily nocturnal in the situations examined. These observations suggest that movement downstream is accomplished either by a displacement of the fry by the current, or by actively swimming with the current, or by a combination of both in some cases.

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Fry migrants have been captured and observed at various locations in the Skeena River drainage of British Columbia since 1954.   This work has provided certain information on the downstream migration under conditions different from those so far reported.

AREA OF OBSERVATION AND METHODS USED

Figure 1 shows the general outline of the Skeena River drainage.   Five species of Pacific salmon are present in this system, although sockeye and pink are most abundant.   Sockeye are most numerous in the Babine Lake system but small runs occur to most other lakes.   At Lakesle Lake in the Skeena drainage,
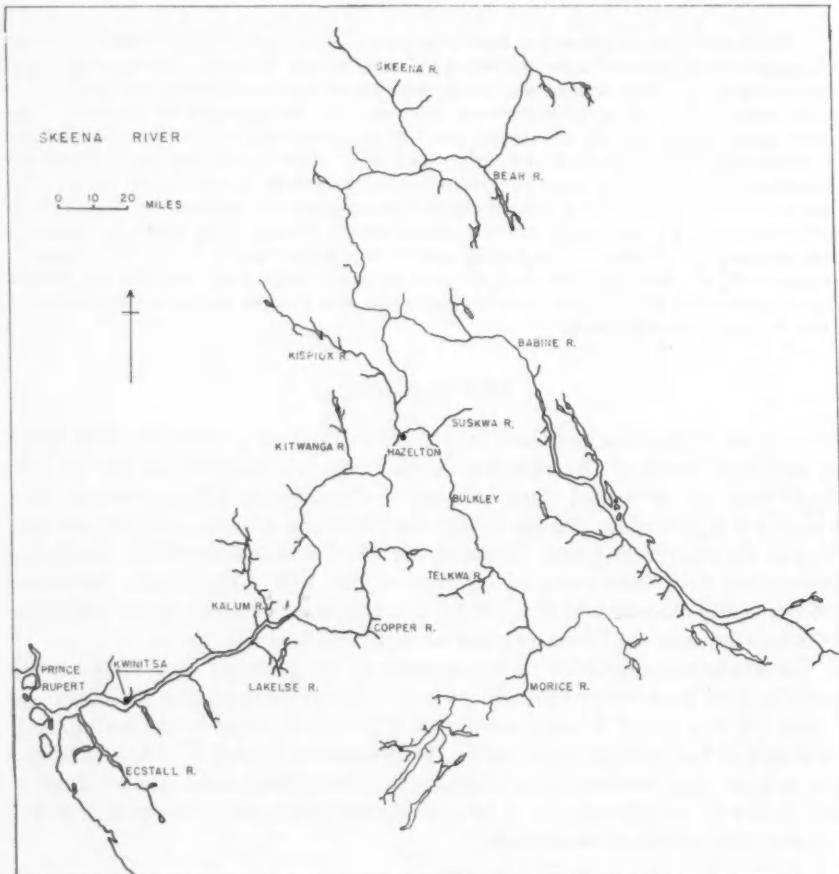
FIG. 1.   The Skeena River drainage.

observations of the sockeye fry migration have been made at Williams Creek. This is the largest tributary in the Lakelse area and the main sockeye spawning stream.

Pink salmon are present throughout almost all of the Skeena system. Their range normally extends as far upstream as the Bear River, which lies about 250 miles from tide water. Observations have been made during the fry migration at several major spawning rivers, the Lakelse, Kispiox, Kitwanga and Kalum (Kitsumgallum) Rivers.

The information was gathered mainly in three ways: (1) by the operation of trapnets, (2) by visual observation at various points along the migration route, and (3) by controlled field experiments. A more detailed description of methods will be given under the appropriate headings.

FRY MIGRATION AND LIGHT

SOCKEYE FRY

SEASONAL AND DIURNAL MOVEMENT. The data were obtained at Williams Creek, Lakelse Lake, during the 1954 and 1955 seasons. This creek in recent years has had from a few thousand to 10,000 sockeye spawners each year. Spawning takes place from the mouth to a point roughly 2.5 miles upstream. Information was obtained mainly by operating small traps across the outlet of the creek. Each trap was 1 foot wide and deep enough (3 feet) to strain the total depth of water. Six traps were placed equidistant from each other across the outlet. The traps were operated continuously throughout the migratory period and the catch was recorded every hour.

A total of 136,276 sockeye fry was captured in 1954. The seasonal migration began in April and terminated in early June. The movement pattern of the fry in relation to day and night for several periods during the season is shown in Fig. 2. This figure is drawn from data given in Table I. Throughout the total period of trap operation the fry were observed to follow a consistent movement pattern. A diurnal periodicity may be said to be characteristic of the run. On any one day the first fry were captured shortly after dark. The number captured per unit time increased steadily until a peak was reached usually 2 to 5 hours after dark. Following the peak, the fry were taken at a progressively decreasing rate and movement ceased with the approach of day.

The time that the greatest rate of movement or peak was observed varied from night to night and also throughout the season. Figure 2 shows the percentage of the run captured during consecutive hours of darkness for different periods of the season. The broken lines show the time of sunset and sunrise. The arrows show the time at which 50% of the night's migration was completed as indicated by trap catches. All times given are Pacific Standard Time.

The seasonal increase in the period of daylight can be seen to have restricted the movement of fry to a progressively shorter period of time. During the migration which took place in early April movement was recorded for 10 hours

each day.   This interval had decreased to about 8 hours by the end of April and
to 7 hours by the end of the season.

The seasonal shift in the time of darkness was accompanied by a shift in
the time of the mid-point of the night's migration.   A difference of about one
hour in the time of sunset occurred from April to early June.   The mid-point
of the night's run was delayed a corresponding length of time.   The mid-point
occurred between 2200 and 2400 hours during mid-April and from 2400 to 0100
hours during late May and early June.

The rate at which the fry were captured after the night's peak also changed
with the season.   About mid-April there was a gradual decrease in the number of
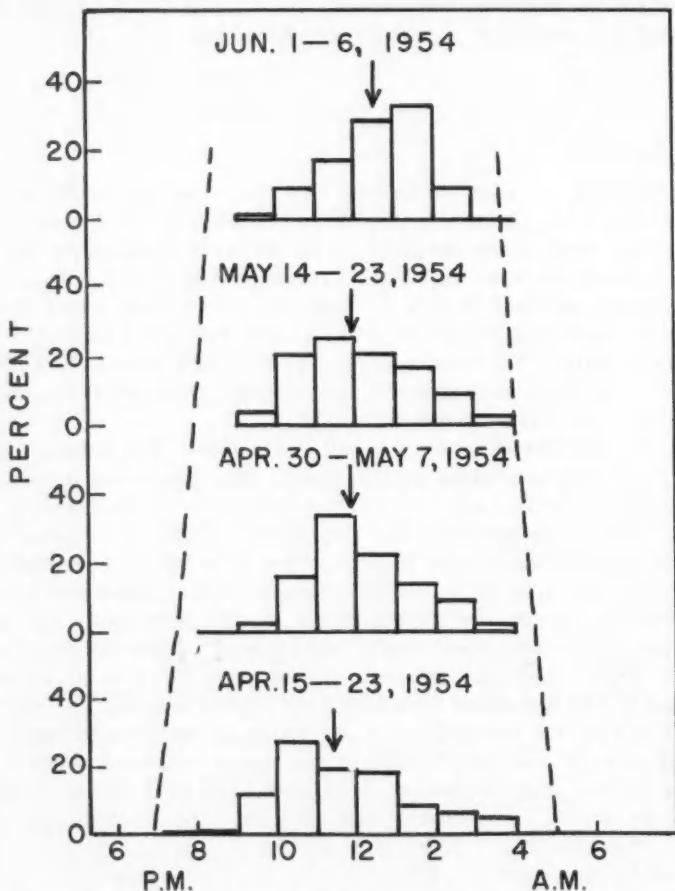
FIG. 2.   The proportion of sockeye fry captured in consecutive hours for
progressive periods of the season.   The arrows represent the mid-points
of the runs.

TABLE I. The catch of sockeye fry and the proportion of the total catch, by hours, in trap number 3, for progressive periods during the 1954 season.

Date	PM hour ending						AM hour ending					Total
	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	
Apr. 15–16	7	2	4	7	3	3	10	3	7	3	0	49
16–17	2	0	1	10	21	9	9	10	0	6	3	71
17–18	0	0	1	18	20	11	1	5	7	15	3	81
19–20	0	0	1	19	49	23	22	25	9	8	0	156
20–21	0	0	2	27	93	29	46	16	8	9	3	233
21–22	0	0	0	12	34	42	36	11	18	0	2	155
22–23	0	0	0	13	37	53	37	14	8	9	1	172
Totals	9	2	9	106	257	170	161	84	57	50	12	917
Percentage	1.0	0.2	1.0	11.5	28.0	18.5	17.6	9.2	6.2	5.5	1.3	
Apr. 30–1	0	0	0	5	27	45	54	47	32	6	0	216
May 1–2	0	0	1	13	35	55	56	47	22	1	0	230
2–3	0	0	2	12	24	70	84	47	54	14	0	307
4–5	0	0	0	25	165	370	233	116	73	21	0	1003
5–6	0	0	3	11	89	169	81	31	18	10	0	412
6–7	0	0	3	11	58	138	55	60	17	4	0	346
Totals	0	0	9	77	398	847	563	348	216	56	0	2514
Percentage	0	0	0.4	3.1	15.8	33.7	22.4	13.8	8.6	2.2	0	
May 14–15	0	0	0	53	243	150	129	99	111	23	0	808
15–16	0	0	0	43	181	225	198	200	146	34	0	1027
16–17	0	0	0	37	127	85	87	67	52	28	0	483
19–20	0	0	0	44	401	535	155	208	103	36	0	1482
21–22	0	0	0	28	185	378	387	222	75	10	0	1285
22–23	0	0	0	43	220	321	438	312	89	17	0	1440
Totals	0	0	0	248	1357	1694	1394	1108	576	148	0	6525
Percentage	0	0	0	3.8	20.8	26.0	21.4	17.0	8.8	2.3		
June 1–2	0	0	0	5	22	97	137	140	54	5	0	460
2–3	0	0	0	11	55	99	121	168	42	5	0	501
3–4	0	0	0	10	24	32	106	87	14	12	0	285
4–5	0	0	0	6	17	30	54	69	23	0	0	199
5–6	0	0	0	1	25	27	59	72	20	3	0	207
Totals	0	0	0	33	143	285	477	536	153	25	0	1652
Percentage	0	0	0	2.0	8.7	17.3	28.9	32.4	9.3	1.5	0	

fry captured in the hours before dawn. As the season progressed the rate of movement fell off more abruptly and by the end of the season the night's migration ended approximately 2 hours after the peak as compared to approximately 4 hours in April. This observation indicates that during the end of the seasonal migration when the hours of darkness were relatively few, the movement of some of the fry may have been halted by the approach of daylight and before movement to the lake was completed.

INITIAL MOVEMENT INTO THE CURRENT. It was found possible under natural circumstances to observe and record the conditions and behaviour of the fry which led to their initial movement from the gravel and into the stream. To study this problem, numbers of fry were introduced into a long, wooden trough and their behaviour recorded.

A trough 16 feet long, 14 inches wide and 8 inches deep (488 × 36 × 20 cm) was placed in a side channel of the creek well away from any disturbances created by the other operations. The ends of the trough were covered with wire screening, thus allowing a flow of water through the trough when it was partially submerged.

The current through the trough was measured by timing the displacement of wooden floats.   The flow was found to be approximately 0.3 ft/sec (9 cm/sec). The bottom of the upstream 2 feet of the trough was covered with coarse gravel. A snug-fitting removable tray was placed in the downstream end to collect fry present there.   In each test 200 sockeye fry, which had been captured the previous night and which had been kept under subdued light, were placed in the upper gravel-covered part of the trough in mid-afternoon.   The fry with only few exceptions remained in the upstream portion of the trough either under cover of the gravel or maintained their position directly over the gravel.   A count of the fry which had moved to the downstream end of the trough was made at 10-minute intervals beginning approximately one hour before dark.   Light intensity was measured at these same time intervals by a model 210 photovolt meter which recorded light intensity to 0.01 foot-candle.   Precautions were taken during these proceedings to avoid alarming the fish either by the movement of the observer or by the use of artificial light.

Six tests were carried out on consecutive nights.   On each occasion a "fresh" group of fry was used.   Figure 3 shows the number of fry which moved from the
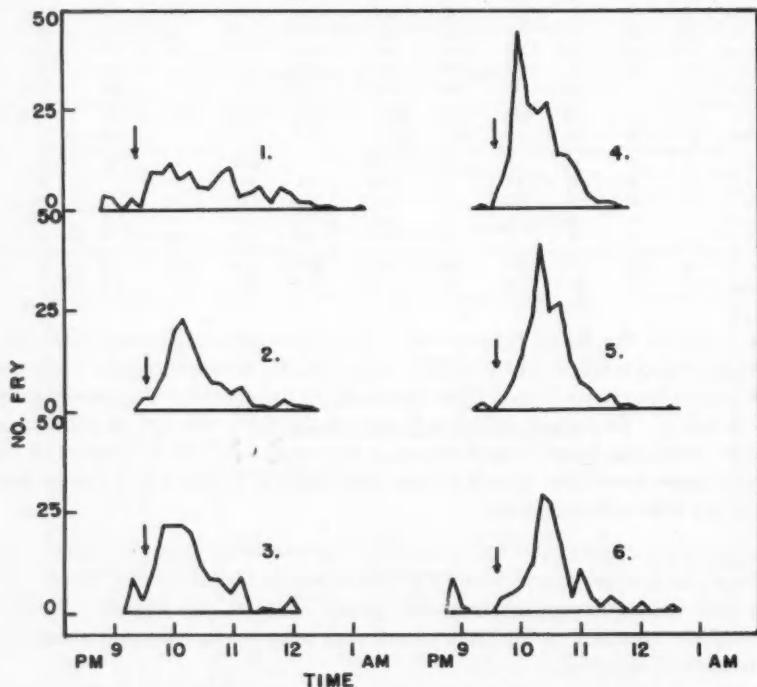

FIG. 3.   The number of sockeye fry initiating movement in consecutive time intervals for six nights.   The arrows represent the time at which the light intensity reached "0" foot-candles.

upstream to the downstream end of the trough during each 10-minute interval. The arrows indicate the time at which the photometer registered "0" foot candles, which would represent illumination less than 0.01 ft-candle. Movement was initiated during each test in the same general way. It began between 2120 and 2130 hours and only after the light intensity had reached the "0" foot-candle level. The few individuals recorded in the downstream end of the trough before that time were those which had moved into that area shortly after being introduced into the trough. The number of individuals which initiated movement during each progressive time interval increased until a peak was reached 60 to 90 minutes later (2220 to 2300 hours). The rate of movement then declined steadily and movement from the upstream end ceased between 150 and 190 minutes after the beginning of the "0" light level (at 2350 to 0040 hours).

Not all the fry moved downstream in each test. Observations were made by using very brief flashes of light from a hand torch. They revealed that fry which had not moved downstream were oriented upstream to the current and maintained their position in the upstream end of the trough. Periodic observations showed that their behaviour remained the same throughout the rest of the night. The proportion not initiating movement varied from 6% to 40%. There appeared to be a tendency for a larger proportion to remain in the upper portion of the trough on cloudy nights than on clear nights. On two cloudy evenings 38% and 40% did not migrate. This may be compared to 22% on a partly cloudy night and 6% and 14% on two clear nights.

The manner in which the fry moved down the length of the trough could not be observed in all its detail as the use of light was restricted to the brief flashes mentioned earlier. It was noted that at the time the light intensity reached "0" the fry were confined to the head end of the trough and appeared to be distributed almost randomly over this area. All were facing upstream but there occurred no net movement upstream. As time progressed the fry tended to spread downstream and to lie over the entire upstream half of the trough rather than in the extreme upstream portion as formerly. Their behaviour was the same however—they swam against the current and maintained their position. After 0030 hours when movement to the downstream end of the trough ceased, the remaining fry were all in the upstream end of the trough.

Three tests were made following those described above in which the trough was kept under illumination for varying lengths of time after darkness normally occurred. At approximately 2030 hours, or one hour before dark, two gasoline lanterns were placed above and alongside the trough. The illumination from these varied somewhat due to variation in air pressure within the lantern but averaged more than 3 ft-candles at the surface of the water in the trough. On the first test the trough was illuminated until 2330 hours, or 2 hours after darkness normally occurred. On the second night the lamps were removed after 3 hours and on the last night the trough was illuminated throughout the whole

night. A record was kept of the number of fry which had initiated movement
from the time the lamps were first placed into position until the following morning.
Figure 4 shows the proportion of the fry which initiated movement in consecutive
units of time on the first 2 nights. The movement pattern during a night when
the fry were subjected only to natural illumination is shown for comparison.
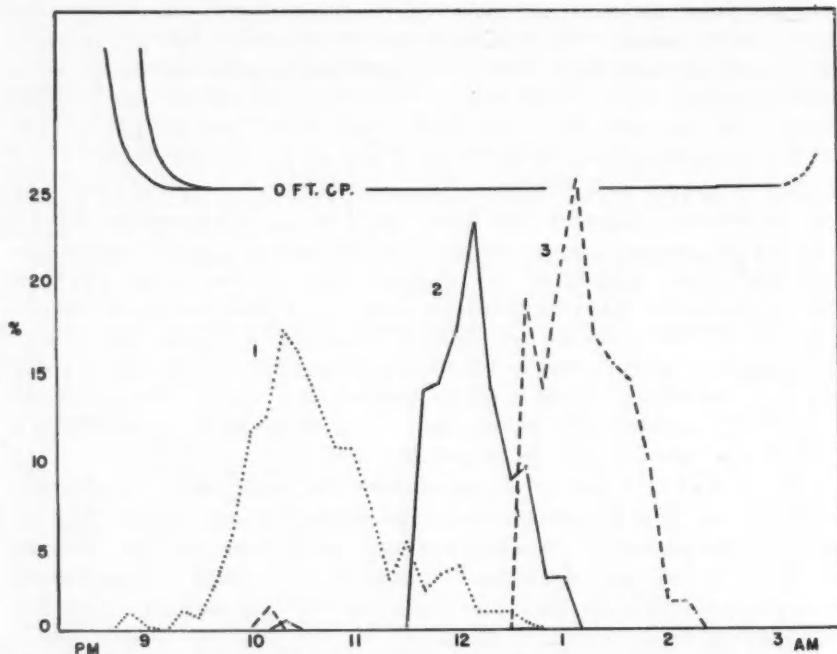
FIG. 4. The movement pattern of sockeye fry under natural illumination (1) and when darkness delayed until 11:30 pm and 12:30 am (2 and 3). The topmost curve indicates the general level of natural illumination during the tests.

The presence of artificial light almost completely prevented the movement of the
fry at their normal time. Upon removal of the lamps, movement was initiated
in a similar manner to that which occurred under normal light conditions. On the
third night, when the trough was kept under continued illumination, only 2 of the
200 fry in the trough were found in the downstream end.

Downstream movement was initiated in a somewhat more abrupt manner
on the nights when darkness was delayed, as compared with nights of natural
light conditions. The period in which the movement occurred was also consider-
ably less (90–100 min compared to 150–190 min). Again not all of the fry
initiated movement. The proportions remaining in the upstream end of the

trough on these nights were 22% and 32%.   This is comparable to the percentages recorded on cloudy "control" nights.

The strong negative response to light on the part of the sockeye was evident during the course of their movement in the stream.   The migrants, regardless of their orientation in respect to current, responded in a well defined manner when subjected to direct light from a lantern or hand torch.   Fry swimming downstream with the current were seen to reverse their direction, sound, and either seek cover in the gravel or attempt to remain in a fixed position over the gravel.   In instances where the fry entered the beam of light swimming against the current their direction remained unchanged, but sounding and a cover reaction occurred as before.

Neave (1955) describes a similar response by pink fry.   He points out the similarity between the behaviour of fry at the coming of day, resulting in complete cessation of movement, and their behaviour when subjected to artificial light. The evidence indicates that the response of the pink and sockeye in this regard is essentially the same.

Coho Fry

The movement of coho fry at Williams Creek was also restricted to the hours of darkness.   In Table II the number and mean proportion captured in the traps in consecutive hours is shown for a 7-day period in 1954.   The movement pattern was similar to that of the sockeye.   The night's run began at dark, built up a peak and then progressively declined.   The migration terminated at daybreak.

TABLE II. The catch of coho fry in consecutive hours of darkness
for 7 days at Williams Creek, 1954.

Date	Number captured in hour ending						
	2200	2300	2400	0100	0200	0300	0400
May 19	5	40	105	40	15	7	0
21	2	13	38	44	15	3	0
22	3	18	22	38	9	5	0
25	5	30	33	46	26	13	1
27	0	23	19	26	20	7	0
28	4	27	33	26	16	15	3
31	0	16	19	41	25	10	0
Percentage captured	2.1	18.4	29.7	28.8	13.9	6.6	0.4

Coho were introduced twice into the experimental trough which was described earlier.   These fry, under natural illumination, initiated downstream movement only after the light intensity had decreased to "0" ft-candle (Fig. 5).   Their movement pattern was comparable to that shown and described for sockeye (Fig. 3).
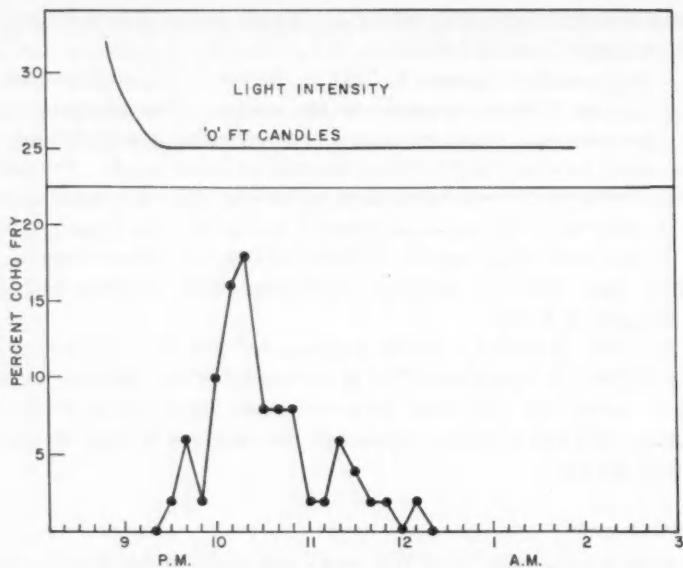
FIG. 5.   The movement pattern of coho fry in consecutive time intervals under natural illumination.   The topmost curve indicates the level of illumination.

The coho were kept under artificial light throughout the night of the second test.   As for sockeye, the presence of the light almost completely halted movement.   Only 6% of the coho fry were found in the downstream end of the trough as compared to 82% in the test under natural illumination.

PINK FRY

The downstream migration of pink fry was examined at 4 different streams in the Skeena area and at 5 different locations on these streams.   Trap-netting was carried out frequently during the emigration from the Lakelse and Kispiox Rivers from 1956 to 1958, the Kalum River in 1956, and the Kitwanga River in 1957 and 1958.

The method used at these locations was only slightly different from that used at Williams Creek.   A small trapnet, 2 ft wide and 1 ft deep (61 × 30 cm) was operated for periods of about 15 minutes at each of several stations across the width of the river.   This procedure was followed at each river for periods of up to 24 hours in length, usually 2 or 3 times each week of the season.

The net was operated so that it strained the top foot of water.

The trapping sites varied to some extent but all were chosen to provide a moderate to fast current and a fairly regular stream bed.   Some of the physical

characteristics of the rivers at the trapping sites are given in Table III. The velocity of the water was measured by timing the displacement of wooden floats at mid-stream. The data are considered representative of a period during "normal" spring runoff.

TABLE III. Some physical characteristics of the trapping sites.

River	Width	Current	Depth	Bottom type
	feet	*ft/sec*	*feet*	
Williams	75	4	2–3	gravel
Lakelse	150	3	1–4	gravel
Kalum	160	5	1–5	large boulders
Kispiox	160	5	1½–7½	rocks, gravel
Kitwanga	70	6	1–5½	mostly gravel

The trapping sites on the Kalum, Kitwanga and Kispiox rivers were located near the river mouths.   Two sites were used on the Lakelse River.   Site 1, which was used in 1956, was located 3.5 miles below the upper end of the pink spawning area.   Site 2, about 1 mile from the mouth and about 7 miles downstream of (1), was used in 1957 and 1958.

Considerable variation in the migration pattern of pink fry was observed. Trap catches at Site 1 on the Lakelse River revealed a nocturnal movement (Fig. 6) which was similar to that described by Neave (1955) on Queen Charlotte Island streams and which was described for Williams Creek sockeye in the
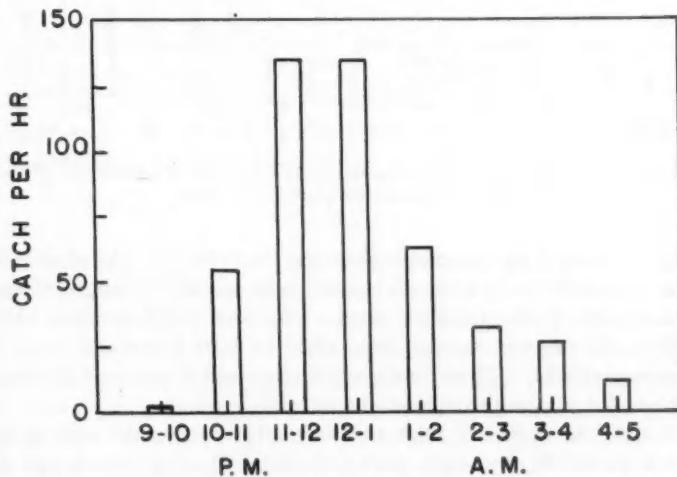

FIG. 6. The catch of pink fry during consecutive hours at the Lakelse River, May 17, 1956.

section above. The fry were first captured at dark. The rate of movement increased to a peak and then steadily declined. The run terminated at daybreak.

The movement of fry at the other locations was found to extend into and throughout daylight hours. Small numbers were captured during the day at the lower Lakelse River site in 1957 and 1958, and at the Kalum River in 1956. Daytime movement reached considerable proportions at the Kispiox and Kitwanga Rivers in all years. Figure 7 shows the catch of pink fry in consecutive time intervals for a 21-hour period at the Kitwanga River in 1958, to illustrate the diurnal distribution.
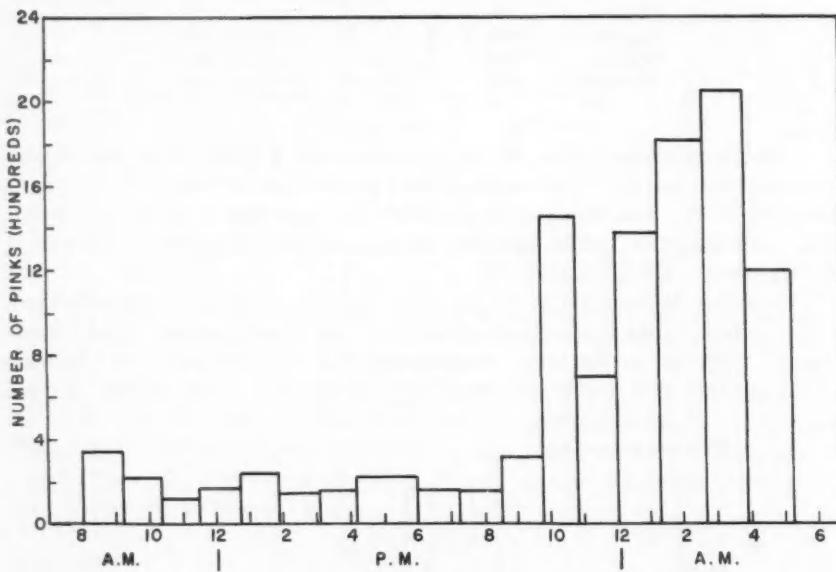
Fig. 7. The catch of pink fry during consecutive time intervals throughout a 21-hour period at the Kitwanga River, May 2–3, 1958.

The proportion of the fry captured during the day and night at each location is given in Table IV along with the approximate maximum length of spawning ground upstream of the trapping sites. Day and night catches have been calculated on the basis of catches from 0500 to 2100 hours and from 2101 to 0459 hours respectively. These time intervals correspond roughly with the periods of daylight and darkness throughout the migratory season.

In general, the degree of migration in daylight increased with increase in the distance which the fry might have travelled. Daytime movement was not observed at the Lakesle Site 1, nor on the Queen Charlotte Island streams that Neave examined. On all these streams the maximum length of the spawning

TABLE IV. The proportion of pink fry captured during the day and night at different locations and the length of the spawning grounds above the trapping site.

River	Year	Proportion of fry captured		Length of spawning grounds
		Night	Day	
		%	%	miles
Lakelse upstream (Site 1)	1956	100	0	3½
Lakelse downstream (Site 2)	1957	90	10	12
	1958	98	2	12
Kalum	1956	69	31	22
Kitwanga	1957	61	39	25
	1958	89	11	25
Kispiox	1956	35	65	55
	1957	53	47	30
	1958	69	31	50

grounds above the trap sites, and therefore maximum distance to travel, was less than 10 miles. At Site 2, where the distance was only slightly greater than 10 miles, up to 10% of the catch was taken in daylight. The percentage became considerably greater, in most instances, when the migration route exceeded 20 miles; it was as high as 65% at the Kispiox River, the longest of the rivers examined.

Daytime movement was found to occur under variable conditions of water and light. Migrants were captured on the Kispiox River on bright sunny days when the river was low and clear. The largest catches, however, were made during periods of high and turbid water. At the Kalum River, where the water is normally turbid due to glacial silting, the proportion of the run captured during the day remained fairly constant despite extremes in water level. This suggests that increased turbidity and the accompanying decrease in light enhance movement during the day rather than changes in water level.

CHUM FRY

Only small numbers of chum fry were captured during the trap-netting and then only on some rivers. The catch of chum over a 24-hour period, April 24 and 25, 1958, at the Kispiox River, occurred almost entirely between 2100 and 0500 hours. Only 9 of the 96 fry taken were captured in daylight. However, only a few days later and following a rise in water, 24 hours of continuous netting resulted in the capture of 232 chum fry, of which 113 or about 50% were taken during daylight.

These data indicate that the downstream migration of chum can either be almost totally nocturnal or it can extend throughout a 24-hour period under certain conditions.

FRY MIGRATION AND CURRENT

LATERAL DISTRIBUTION

Trap operation at a number of different stations across the rivers has provided much of the information to be reported. In addition, many observations were made at the trap sites and other locations along the migration routes.

It was apparent shortly after the operation began that the relative catch of sockeye and pink fry at the different stations could be predicted fairly well by the position of the trap in relation to the current. The greatest number of these fry were captured in traps located in the fastest water, generally near the centre of the stream. Smaller numbers were taken in traps closer to the banks. The catches of coho fry, however, did not appear to be related to current in the same way, or at any rate not to the same degree. The mean proportion of fry captured in each trap at Williams Creek in 1954 is shown in Fig. 8, from data in Table V.
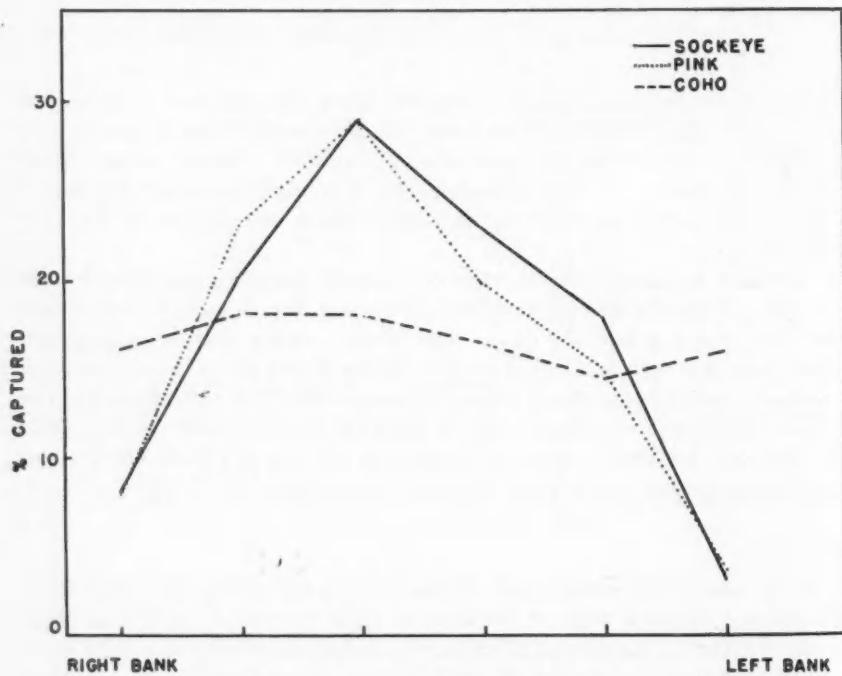
FIG. 8. The mean proportion of fry captured in traps located across the main channel of Williams Creek, 1954.

In order to examine more closely the relationship between the observed lateral distribution of the fry and water velocity, current measurements were made almost daily at each trap station at Williams Creek. Average water velocity was measured by using the standard technique with a Gurley-Price meter.

TABLE V. Mean velocity of water at the six Williams Creek traps, and the number and proportion of fry captured in each trap for a 56-day period, 1954.

Trap No.	Av. velocity of water	Sockeye salmon		Pink salmon		Coho salmon	
	feet/sec	no.	%	no.	%	no.	%
1	1.91	8363	8.0	282	8.3	476	16.3
2	2.36	20921	19.9	789	23.1	537	18.4
3	2.56	30175	28.8	996	29.2	528	18.1
4	2.21	23667	22.6	702	20.5	485	16.7
5	2.08	18528	17.6	524	15.3	424	14.6
6	1.39	3241	3.1	123	3.6	462	15.9
Total		104,895		3,416		2,912	

Table V gives the mean velocity recorded at each trap and the number of fry captured in each trap. A statistically significant relationship was found to exist between the two variables: for sockeye and pink, respectively, $r = 0.95$ and 0.96, d.f. = 4, $P < 0.01$. Figure 9 shows the relationship observed between water velocity and the distribution of fry catches in Williams Creek. The number of sockeye and pink fry captured in each trap was closely and positively related to the current at the trap site. Direct proportionality, however, did not exist: the data can be extrapolated to a threshold at 1.3 ft/sec (0.4 m/sec). Above that velocity both the actual number of fry captured, and the number per unit volume of water strained, increased with increase in velocity.

The relationship between coho fry catches and current was not significant ($r = 0.60$, d.f. = 4). The catches of coho, unlike those of sockeye and pink, were distributed more or less uniformly across the width of the river.

Chum salmon fry appeared to be distributed similarly to coho at the one site where they were studied. A total of 178 chum were captured on the Kitwanga River throughout a night of trapping in 1958. The fraction of the fry captured in each of 4 traps strung across the river, from the left to the right bank, was
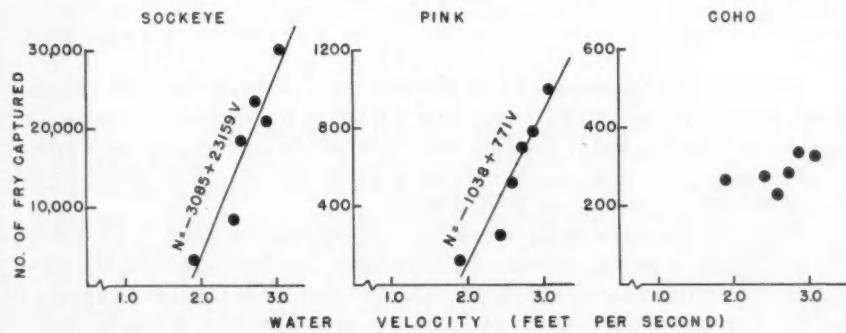

FIG. 9. The relationship between fry catches and current at six Williams Creek traps.

27.5, 31.5, 24.7 and 16.3%, respectively.   The distributions of the catches of chum and coho suggest that these fry may actively "choose" their position in the stream to some extent: i.e., they tend to be more numerous, per unit volume, at the sides of the river, since catches are just as high there in the slower current.

VERTICAL DISTRIBUTION

The vertical distribution of pink fry migrants was examined during a short period of the 1958 migration at the Lakelse and Kispiox River trapping sites. Small, cone-shaped nets, 8 inches (20 cm) in diameter at the mouth, were suspended at up to 1-foot intervals from the surface to the bottom of the water. The nets at all levels were operated simultaneously.   A total of 32 night tests and 27 day tests were made on the Kispiox River and 5602 pink fry were captured. Only night tests were made on the Lakelse River.   Here, 24 tests were made in which 2401 fry were taken.   The data are summarized in Table VI.

TABLE VI. The number of pink fry captured in daylight and darkness in various depths of water. The depths shown indicate the distance from the river bottom to the centre of the 8-inch nets (1 inch = 2.54 cm).

Places and total depth of water	Number of pink fry captured at various distances from the stream bottom										
	Net position during darkness (*inches* above bottom)						Net position during daylight (*inches* above bottom)				
	56	44	32	20	14	8	56	44	32	20	8
	no.	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*
Kispiox R 5 *ft* (1.5 *m*)	94	281	188	494	...	144	169	399	84	132	20
Lakelse R 5 *ft* (1.5 *m*)	31	111	387	499	...	21	...	...	...	...	...
Kispiox R 4 *ft* (1.2 *m*)	...	27	160	527	...	479	...	292	550	311	50
Kispiox R 3 *ft* (1.2 *m*)	...	...	73	155	...	272	...	...	434	244	23
Lakelse R 3 *ft* (1.2 *m*)	...	...	291	309	255	47	...	...	...	...	...
Lakelse R 2 *ft* (0.6 *m*)	...	...	...	283	160	57	...	...	...	...	...

The nets were operated in water varying from 2 to 5 feet deep (60–150 cm). Water velocity at the surface varied from 3 ft/sec in the shallower water to 6 in deeper water (1–2 m/sec).   The nets were operated during each test for a period of time sufficient to result in the capture of about 100 fry.   This period varied from a few minutes to as long as 30 minutes.

Figure 10 shows the mean proportion of fry which was taken in the nets at different levels below the surface.   No adjustment has been made for the effect of decreasing water velocity with depth, which would tend to result in an apparent decreased catch at lower depths per unit of time.   The data, however, clearly show that the pink fry were located throughout the total depth of the river both
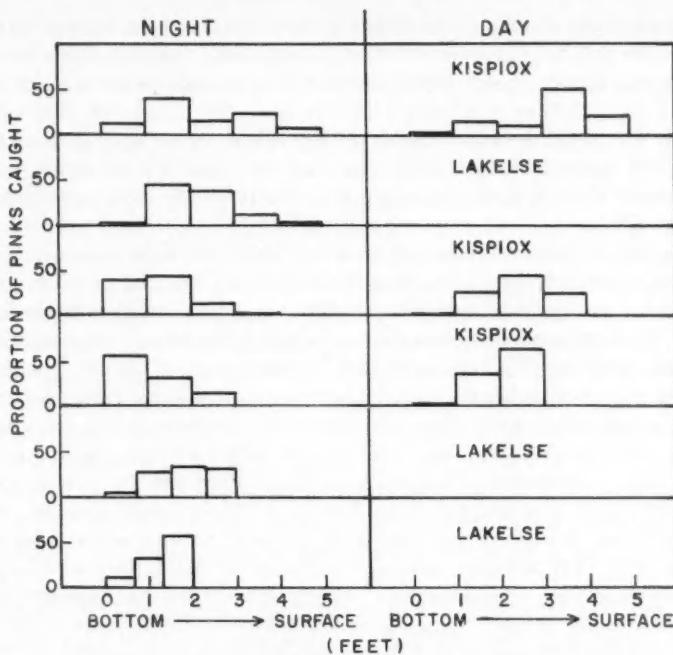
FIG. 10.   The proportion of pink fry captured at different depths of the
Lakelse and Kispiox Rivers, 1958.

by night and by day.   The night tests indicate that where the river was 5 feet
deep the fry were most numerous in the middle layer of water.   In shallower
water the fry must necessarily move closer to the surface and in 2 and 3 feet of
water most of the fry were found in the top foot.

Figure 10 also shows that a relatively greater proportion of the fry was
taken closer to the surface during the day than during the night.   In daylight
the fry were more concentrated in the top 2 feet of water where the total depth
was 4 and 5 feet.

SCHOOLING

Schooling of the four species studied was not observed to occur for most
of the downstream migration.   Individuals but not schools were occasionally
seen in the spawning streams, both during daylight and during darkness.   Trap
catches also did not indicate any schooling at these places.   The number captured
per unit of time was quite consistent, keeping in mind the effect of changes in the
diurnal and seasonal abundance of the migrants.   If schooling occurred to any
great extent it would be expected that this would be reflected in considerable
variation in the number captured in the traps, at least during the few minutes
between the times that the traps were inspected.

Some schools of chum fry, however, were observed during the day at the mouth of the Lakelse River and further downstream in side channels and sloughs of the Skeena River. Some schooling therefore occurred prior to entry into salt water.

Coho fry were often seen either as individuals or as aggregations in many streams and rivers. Many of these fish normally take up residence in streams for extended periods and their behaviour is probably not representative of migrating fish.

Schooling of pink fry was not observed until the tidal zone of the Skeena River was reached. This area, near Kwinitsa (see Fig. 1), is up to 160 miles (260 km) downstream of the major spawning areas. It is within the limits of the tide but it is not known if there occurs an actual influx of salt water at this point.

Small numbers of pinks could be captured during the day at Kwinitsa by towing a trap net behind a boat. The fry, however, could only be seen during the time of the high slack tide. At this time the current was slackened considerably and the river became covered with large, smooth "boils" up to 100 feet (30 m) in diameter. Thousands of pinks were seen on several occasions to rise to the surface as individuals and swim at the surface in a random manner. These fry upon encountering others were observed to form small schools up to about 12 fish. The schools continued to move at the surface and apparently at random in relation to the current. When alarmed by the approach of a boat the schools would "sound" to a depth beyond observation (only a few inches) or the school would break up and the fry would sound individually.

Fry could be observed here for a period of a few minutes to one hour at the high slack tide. With the ebb of the tide and the increased velocity of the current, the fry could no longer be seen.

FEEDING ACTIVITY

A number of pink fry migrants were taken at several points along the migration route. Their stomachs were examined for evidence of feeding, (Table VII).

TABLE VII. Stomach analysis of pink migrants 1956 and 1958 taken at the various trapping sites.

River and year	Fry examined	Fry with stomach contents		Proportion of contents		Stomachs with food organisms
				Inorganic	Organic	
	no.	*no.*	%	%	%	%
Lakelse, 1958	236	29	12	82	18	2
Kitwanga, 1958	261	27	10	74	26	3
Kalum, 1956	54	17	32	65	35	11
Kispiox, 1958	1891	194	10	60	40	4
Kispiox, 1956	80	41	51	50	50	25
Skeena, 1958	51	23	45	22	78	43
Skeena, 1956	40	27	68	0	100	68

At all places where samples were taken some proportion contained food organisms and/or foreign inorganic material in their stomachs. Of the 1891 fry collected from the Kispiox River in 1958, 10% had foreign material in their stomachs and 4% contained food organisms. The contents other than food organisms consisted almost entirely of sand and very small pieces of gravel. A higher incidence of feeding was indicated by the 1956 sample from this same river. About 50% of the fry were found to have material in the stomachs and 25% contained food organisms. The samples from the Lakelse, Kitwanga and Kalum Rivers indicated that from 1% to 11% of the fry contained food organisms and from 10% to 32% contained both organic and inorganic substances.

The small number examined from the Kwinitsa area of the lower Skeena River indicated an increase in the proportion containing food in their stomachs here as compared to further upriver. The Kwinitsa samples showed that 43% and 68% of the fry contained food organisms as compared to a high of 25% elsewhere. The proportion in the Kwinitsa samples containing inorganic material was almost negligible as compared to the "upriver" samples.

The food organisms found in the stomachs of the pink fry were mainly the larval and nymphal forms of freshwater mayflies, stoneflies, craneflies and midges. Small numbers of Hydracarina (red water mites) were found in fry from the Kalum River.

The results demonstrate that pink salmon fry may begin to feed not only during their migration to the sea but also at a fairly early stage of the migration. The presence of sand grains in the stomachs might suggest that the intake of food could be accidental, that is, swept into the mouth during passage through turbulent water. However, the high incidence of food organisms found in the stomachs of the Kispiox River and Kwinitsa fry strongly supports the view that feeding and its associated activity begins in fresh water.

DISCUSSION

Sockeye, pink, coho and chum fry appear to follow a similar behaviour pattern at least during the initial stage of their migration downstream. Their movement was nocturnal and it appeared to be rather precisely regulated by light and changes in its intensity. The fry were found, either throughout the whole of their migration or during the early stage of it, to begin movement at dark and terminate downstream movement at the approach of day.

The movement of sockeye and coho fry appeared to be initiated by the rapid decrease in light intensity at nightfall. They were observed in the experimental trough to move from their initial position at the upstream end within a period of 2.5 hours following a reduction in light intensity from a daytime level to "0" foot-candles (less than 0.01). It was also observed that the use of artificial light delayed or almost entirely prevented movement downstream, at least for one night.

The data strongly suggest that the movement of the sockeye and coho from the gravel and into the current is largely the result of some or total loss of visual contact at dark. Hoar (1958, p. 423), after observing the behaviour under similar conditions, concludes: "The significant point is that reactions which orient fish both in the current and in their hiding places among stones during the day will be reduced at night—particularly when the fish rise toward the surface—and that fish losing direct contact with the bottom will swim or drift with the current". Hoar noted that a schooling reaction was associated with this movement. "Presently some members of the group drift downstream somewhat losing position, whereupon others turn and swim with them (schooling reaction). The entire group then swim down the trough, actively oriented and travelling with the current". Schooling activity was not observed in the experimental trough at Williams Creek. Both sockeye and coho were seen to be "displaced" as individuals while oriented positively to the current.

The initial movement of pink and chum fry was not observed. However, their nocturnal movement pattern was found to be similar to that of the other species, suggesting that pink and chum are also displaced into the current when visual contact can no longer be maintained.

Once into the current, the downstream migration appears to continue until the nursery area is reached or daylight approaches. During this migration the lateral and vertical distribution of the fry can be considered to be a result of their activity in response to factors such as light and current, and/or a result of the direct effect of water velocity and turbulence. Their activity and distribution could therefore vary considerably from one point of observation to another depending upon the physical conditions operative at each point. At Williams Creek, the lateral distribution of sockeye and pink fry migrants was closely and positively related to water velocity. The greater the current, the greater the catch, and the greater the density of the fry per unit volume of water. This situation may arise from a "preference" on the part of the fry for fast water, or during the course of the journey the fry may be swept into and carried along by the greatest current.

The vertical distribution of pink fry migrants was observed at two locations with water up to 5 ft (1.5 m) in depth and where the surface current ranged from 3 to 6 ft/sec (1–1.8 m/sec). In darkness and in relatively deep water the fry were found dispersed throughout the total depth of water but they were captured in greatest numbers at intermediate depths. During the day the largest catches were made somewhat closer to the surface. This difference in distribution indicates that the fry possess some ability to maintain a preferred depth.

The change in current speed with depth was not recorded. However, the current is generally fastest near the surface and slowest near the bottom due to the drag of the stream bed. The largest catches of pink were at intermediate depths and probably not in the swiftest water—unlike the situation in respect to

lateral distribution.   However, the vertical distribution observed could possibly arise from "mixing" due to water turbulence during the course of their journey.

The catches of coho and chum fry indicate that these two species are distributed almost uniformly across the river.   This suggests that chum and coho actively "choose" their position in respect to current to some extent.

Most of the fry probably complete their migration from the stream in one night where the route is only a few miles long.   In longer streams, the migration is often halted as day approaches.   The fry are once again capable of establishing firm visual contact with their surroundings and a preferred position in respect to light and current can be maintained.   However, the migration of at least some of the pink and chum fry commonly continued into and throughout the day.   In some instances the pink migration continued on bright sunny days when the water was low and clear and when there was little doubt that visual contact with the surroundings could have been maintained.   This indicates that the response of the fry to light had changed from the negative response which led to the former purely nocturnal movement.   The degree of this change in the response of pink fry to light appeared to be related to the length of light exposure.   The largest daytime migration was observed on the longest rivers and here the greatest amount of time was required for the movement downstream.   The Kispiox River spawning area extends up to 55 miles (89 km) in length.   If it is assumed that the mean rate of travel of the pink fry migrating from this river is equal to the mean current, then on the basis of a mean velocity of 3 ft/sec (1 m/sec) the length of time required to travel the distance from the extreme upper end of the spawning ground to the river mouth would be roughly 18 hours or what would amount to two full nights of purely nocturnal movement. As considerable daytime movement was observed, the response of pink fry to light appears to change very shortly after migration begins and probably during the first day of exposure to light.

The daytime movement of chum fry indicates that a similar change in the response to light occurs within this species.

No change from the negative response to light of sockeye fry was observed at Williams Creek.   However, in other areas where the sockeye spawning ground is located below the outlet of a lake, some sockeye fry are observed to migrate upstream in schools during the day.   Hoar (1958) points out that sockeye at some period after emergence from the gravel remain exposed at higher light intensities.   There is no doubt then that this change in response to light also occurs in sockeye fry.

This change from the negative response to light can be considered a pre-requisite for schooling and feeding, both of which are dependent at least to a considerable extent on the visual process.   Although light may not be avoided to the extent it was formerly, and thus schooling and feeding are made possible, the opportunity to carry out these activities may not immediately present itself due to the often turbid and turbulent waters of the migration route.

Pink fry were found to feed to some extent in the tributary rivers of the Skeena but were not observed to school there.   Farther along their migration route,

in the lower reaches of the Skeena River, the proportion of pinks which were feeding was relatively high and schooling was observed for the first time. Conditions favourable to schooling and feeding of these fish are therefore probably not normally encountered until the tidal zone is reached.

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An Attempt to Improve Trout Fishing in a New Brunswick Lake by Deferment of Opening of Angling Season[1]

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ABSTRACT

Deferment of opening of angling season for brook trout at Crecy Lake, New Brunswick, from April to June 1, resulted in much improved angling in early summer. The improvement was relatively minor in July and August. Earlier removal of stock and adverse effects of high water temperature on feeding of trout conditioned the poorer midsummer angling. There was a lower survival of planted trout to anglers' catches with the late opening.

INTRODUCTION

A MAJOR PORTION of the annual crop of brook trout (*Salvelinus fontinalis*) from lakes in New Brunswick and Nova Scotia is removed by resident anglers during the spring months. Reasonably good angling is also desirable during the summer as well, particularly in the promotion of the sport fishery as a tourist attraction. In 1956 the opening of the angling season at Crecy Lake, Charlotte County, New Brunswick, was deferred from April 15 to June 1. The object was to learn what quality of trout angling might be realized in summer by this direct action to conserve the supply of trout in the lake against early season fishing.

CONDITIONS UNDER WHICH THE TEST WAS MADE

A limnological description of Crecy Lake has been given by Smith (1952). It is a headwater, unstratified lake with an area of 20.4 ha (50.4 acres), a mean depth of 2.4 m (7.8 ft), and a maximum depth of 3.8 m (12.5 ft). Bottom water temperatures (at approximately 3.5 m), recorded during the angling seasons of 1949–56, are plotted in Fig. 1.

A program of stocking, fertilization and predator control at Crecy Lake assured a good population of brook trout for angling (Smith, 1955, 1956). Trout were prevented from leaving the lake by a trap situated in the outlet. This trap was maintained throughout the year.

The watershed and shores of Crecy Lake are entirely forested. Ready access to the lake is only by a wood-road. A technician is resident at the lake throughout the year. Almost all of the angling was from boats that were under control of the technician. Accordingly, it was possible to exercise control of the angling and to obtain very near complete, if not complete, creel censuses.
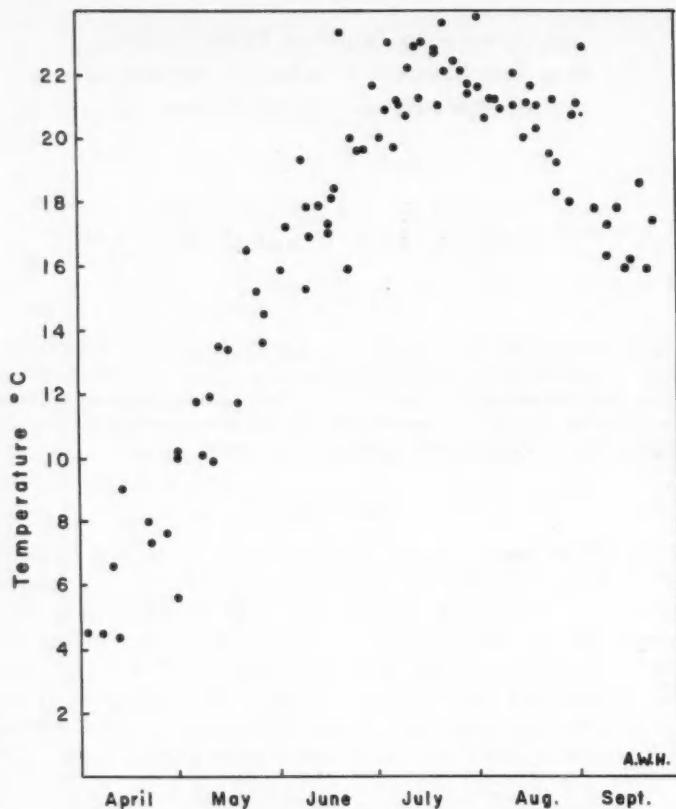
Fig. 1. Bottom water temperatures in Crecy Lake during the angling seasons of 1949–56.

In 1955 the official angling season for brook trout in most waters of New Brunswick was from April 1 to September 15, both dates inclusive. The official season was shortened so that in 1956 and 1957 it did not open until April 15. Specifically for Crecy Lake in 1956, the opening of the season was deferred to June 1.

ANGLING METHODS AND PROPORTIONAL EFFORT

The methods of angling, and the proportion of effort by each, were quite comparable for the years under consideration (Table I). Still-fishing with bait (usually earthworms) from anchored boats was the most popular method of fishing. This mode of fishing accounted for 86 to 94% of the effort during the years 1955–57, and for 87 to 94% of the catches. A relatively small part of

TABLE I. Catch of trout from Crecy Lake by different modes of angling.

	1955			1956			1957		
	No. caught	Rod-hours	No. per rod-hour	No. caught	Rod-hours	No. per rod-hour	No. caught	Rod-hours	No. per rod-hour
Still fishing	5,187	1,574	3.3	2,586	1,350	1.9	4,194	2,196	1.9
Fly fishing	301	94	3.2	304	119	2.6	284	68	4.1
Trolling	39	29	1.3	34	59	0.6	72	61	1.2
Unclassified	105	39	2.7	65	41	1.6	66	18	3.7
Totals and averages	5,632	1,736	3.2	2,989	1,569	1.9	4,616	2,343	2.0

TABLE II. Angling statistics for brook trout at Crecy Lake.

	Apr. 1–15	Apr. 16–30	May 1–15	May 16–31	June 1–15	June 16–30	July 1–15	July 16–31	Aug. 1–15	Aug. 16–31	Sept. 1–15	Totals and Averages
1955												
Number caught	1,598	1,829	1,431	412			Closed to fishing					5,632
Number of rods	112	158	168	78								655
Number per rod	14.3	11.6	8.5	5.3								8.6
Number of rod-hours	219	386	549	228								1,736
Number per rod-hour	7.3	4.7	2.6	1.8								3.2
1956												
Number caught					1,987	444	345	109	61	13	30	2,989
Number of rods					251	102	83	44	39	11	7	573
Number per rod					7.9	4.4	4.2	2.5	1.6	1.2	4.5	5.2
Number of rod-hours					791	270	292	101	82	18	15	1,569
Number per rod-hour					2.5	1.7	1.2	1.1	0.7	0.7	2.0	1.9
1957												
Number caught	...*	1,946	932	877	495	158	112	31	28	28	9	4,616
Number of rods	...	297	129	174	79	31	23	31	29	10	5	808
Number per rod	...	6.6	7.2	5.0	6.2	5.1	4.9	1.0	1.0	2.8	1.8	5.7
Number of rod-hours	...	861	388	466	247	99	82	106	62	20	12	2,343
Number per rod-hour	...	2.3	2.4	1.9	2.0	1.6	1.4	0.3	0.5	1.4	0.8	2.0

*Angling season not open until April 15.

the effort and catch was by fly-fishing and by trolling with spinners with baited hooks. Of the fly-fishing done, it proved on the whole to give the best catch per unit of effort. Most of the unclassified angling was probably still-fishing.

EFFECTS OF DEFERRING THE OPENING OF THE ANGLING SEASON

SEASON OF CAPTURE

Brook trout are readily taken by anglers from lakes when the water temperature is low (from our personal experience at least down to 3–4°C). This aspect of the behaviour of trout is well known to anglers, and they exert a strong fishing pressure on New Brunswick lakes as soon as the season opens in April. Creel censuses maintained on eight Charlotte County, New Brunswick, lakes (including Crecy) during the years 1941–47 showed that 77% of the fishing effort was applied and 79% of the catch by number was made in April and May (Smith, 1952). A quite similar situation obtained at Crecy Lake in 1955 and 1957 (Table II, Fig. 2). For these two years combined, 76% of the effort and 88% of the catch were in April and May. In all of these instances, both the effort and catch declined as the seasons progressed into and through the summer.
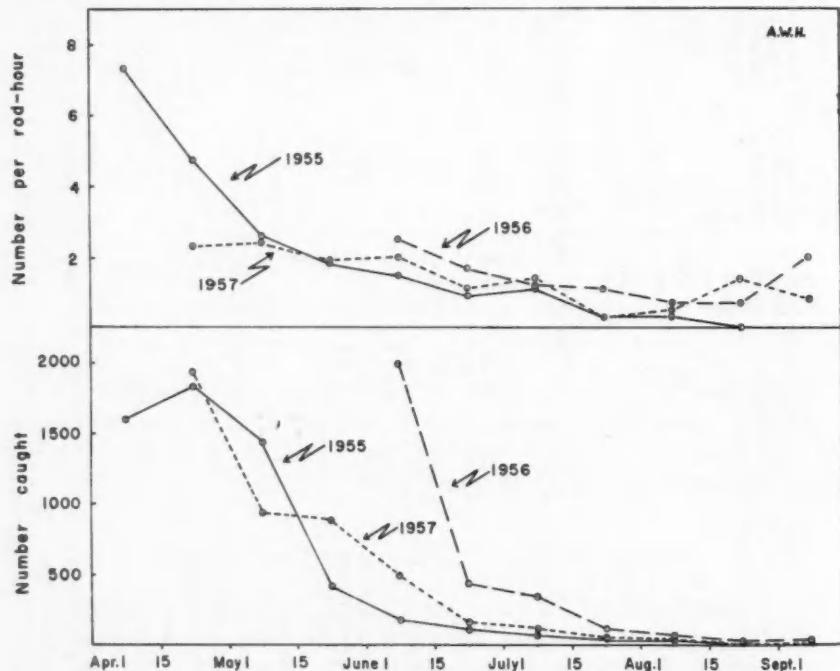
FIG. 2. Anglers' catches of brook trout by number and per rod-hour at Crecy Lake during the season 1955–57.

In 1956, as already noted, Crecy Lake was closed to angling until June 1. Trout anglers of the area were quite aware of this action. There resulted a heavier angling pressure during June than was usual in other years. Data in Table II show that 68% of the effort and 81% of the catch for 1956 were in June. Thus, to a large extent, deferment of the opening of the angling season to June 1 resulted only in postponing the usual fishing pattern to this later date. The outcome was a much larger catch of trout in early summer. However, the marked improvement was rather short-lived. Although the catch continued to be higher into July than in the other two years, it was not particularly noteworthy (Table II, Fig. 2).

SUMMER ANGLING SUCCESS AND CATCH

An important factor in the decline of angling success and catches to relatively low levels by midsummer in any of the years was removal of large numbers of trout from the lake by anglers earlier in the season. There was no recruitment to the number of trout in Crecy Lake during the angling seasons. For the years herein concerned, almost the entire supply of trout came from plantings of under-yearlings (marked by fin-clipping) made in early September of each year (Table III). Planted trout were marked by removal of the adipose and one of the paired fins, right ventral in 1954, left pectoral in 1955, and left ventral in 1956. High survival of other trout, variously fin-clipped, at Crecy Lake (Smith, 1955), and equal survival of unmarked and marked (adipose and left pectoral) trout held over winter in a rearing pond (Smith, 1952), suggest that the diverse fin-clipping of the fish herein considered resulted in no serious differential mortalities.

Spawning occurred in the littoral zone of Crecy Lake, but conditions were not favourable, with the result that progeny from natural spawning contributed few fish to the anglers' catches. Some but unassessable recruitment may have occurred during each angling season by growth of the smaller trout to a more catchable size. The average length of the trout at planting and at capture by anglers is given in Table III.

Another factor that bears on poor angling for brook trout during summer months is the effect of water temperature on movements and feeding activity of the fish.

MOVEMENTS. It is a rather common observation that brook trout move into cooler waters, if they can, when temperatures approach and rise above 20°C (Elson, 1942; Baldwin, 1948; Smith and Saunders, 1958). Obviously, continuance of angling into summer in waters that have largely been vacated by trout would yield poor catches. Contrarily, observant and knowing anglers may experience good summer trout fishing when they put their effort on springholes and other relatively cool waters.

At Crecy Lake, coincident with the highest water temperatures, numbers of trout, although at no time large, were observed to congregate in very shallow water on shore, where a cool seepage came from an adjacent wooded swamp. For the most part however, it would appear that the trout population remained

TABLE III. Number and average fork length in centimetres of trout at Crecy Lake when planted and when captured by anglers, and percentage survival to anglers' catches.

Year of planting (at age 0)	Number planted	Number captured			Percentage surviving to anglers' catches
		Age I	Age II	Age III	
	no. cm	no. cm	no. cm	no. cm	%
1954	13,227 (10.8)	5,477 15.6	71 27.5	1 31.8	42
1955	13,540 (8.5)	2,918 15.1	231 23.9	0	23
1956	12,970 (9.5)	4,349 15.1	155 27.0	4 40.4	35

TABLE IV. Estimates of trout populations in Crecy Lake from recapture of marked fish.

Number marked at or near beginning of angling season	Number of marked trout recaptured during season	Total catch after marked trout introduced	Estimated number present when marked trout introduced	Estimated 95% fiducial limits of number of trout present when marked trout introduced		Estimated number of trout present at end of season
				Upper	Lower	
1955						
252 (April 12)	191	4,459	5,883	6,757	5,080	1,424
1956						
206 (June 1)	121	2,918	4,967	5,922	4,137	2,049

in the open waters of the lake where in July and much of August they were subjected to water temperatures well above 20°C, but still sub-lethal (Fig. 1). Fry (1951) gives 25.3°C as the lethal temperature with prolonged exposure for fully acclimated brook trout.   For the majority of trout in Crecy Lake in summer there was little chance of escape from the higher water temperatures.

FEEDING ACTIVITY.   Hoar (1942) and Baldwin (1957) found that the feeding activities and food consumption by brook trout were depressed markedly by temperatures appreciably above 20°C.   At high, yet apparently sub-lethal water temperatures, Hoar noted that trout ceased to feed.   He further observed: "If feeding is entirely suspended because of high temperature, it may not be resumed when the temperature again falls within the normal range.   The fish must have sufficient time to recover at a lower tempearture".   Sufficient recovery time for commencement of feeding again was several hours, or an indefinite period, depending upon the degree and extent of temperature fluctuations.   Thus, in addition to the smaller supply of trout left in Crecy Lake by July and August, it appears probable that decline in feeding activities at summer temperatures was also an important factor conditioning the poor angling in midsummer.   It is a general experience, but not documented, that trout angling improves in New Brunswick lakes with falling water temperatures in early autumn.   The angling effort is much less, however, than in the spring months.   There is the suggestion from Fig. 2 that the angling success improved in late August and September at Crecy Lake, but the fishing effort was too low for the data to be really indicative.

Early-season angling (even when deferred to June 1) removed, as we have seen, large numbers of trout, but there is evidence that a reduced, yet appreciable population was present in Crecy Lake during July and August in each year. Anglers captured 71, 515 and 171 trout during these two months in 1955, 1956 and 1957 respectively, albeit angling success was relatively poor (Table II). Trout, not more than 50 in any one day, were observed in autumn at spawning time during the three years in the littoral zone of the lake.   There was a carry-over from age I to age II (Table III).   Estimates of trout populations were also made by the mark-and-recapture method in 1956 and 1957.   In these two years trout were caught on barbless hooks just before or after the angling seasons opened, additionally marked by removal of part of the dorsal fins, and then released, after being held up to eight hours to eliminate obviously injured fish. Estimates of populations are presented in Table IV.   These indicate about 1,400 and 2,000 trout present in the lake at the close of the angling seasons in 1956 and 1957.   Of the conditions to be met in making such estimates (Ricker, 1958), that of equal natural mortality among the marked and unmarked fish may have been least fulfilled.   If the natural mortality of the marked trout was greater, then the population estimates would be high.   Possibly the low survival of trout to age II points to such having occurred (Table III).   (Fiducial limits have been placed on the estimates in Table IV (Chapman, 1948) with the assumption, perhaps poorly made, that there was no, or negligible natural mortality

among the trout over the time periods involved in the estimates.)   In any event, the above observations and estimates lend credence to the view that the poorer angling success in midsummer was due more to adverse temperature effects upon feeding than to a dearth of fish in the lake.

SURVIVAL TO ANGLERS' CATCHES

Data on the survival to anglers' catches of underyearling trout planted in Crecy Lake in early September 1954, 1955 and 1956 are set forth in Table III. By far the best survival was to capture as yearlings (age I).   Relatively few of the planted trout survived to be taken at age II or older.

Data given in Table III on the survival to anglers' catches from the 1954 planting of trout are not strictly comparable to those for the two subsequent years.   In 1954, 110 yearling trout were removed from Crecy Lake by gill-netting in late summer and early autumn (Smith, 1956).   The underyearling trout planted in September 1954 were accordingly subjected to reduced cannibal-ism, and there followed the high survival of those planted trout to the anglers' catches to be noted in Table III.   The gill-netting was not repeated in 1955 and 1956.   Aside from the difference in the length of angling season, and effects therefrom, the plantings made in these two years experienced quite comparable conditions.

A lower survival of the trout planted in 1955 to anglers' catches was associated with keeping Crecy Lake closed to fishing until June 1 in 1956 (Table III).   The difference from the higher survival experienced in 1957, when angling started on April 15 (35% as against 23%), is taken as sufficiently large to suggest strongly that the late opening had a significantly adverse effect, quite apart from possible seasonal variation in the Crecy Lake environment.   Accordingly, what was gained in providing better early summer angling by the late opening of the angling season was materially offset by a poorer survival of planted trout to the anglers' catches.

SUMMARY

Most brook trout are captured by anglers in lakes of the Maritime Provinces of Canada during April and May.   An attempt was made at Crecy Lake, New Brunswick, to improve summer angling by not opening the fishing season until June 1 in 1956.   Creel census results for that season were compared to those obtained in 1955 and 1957 with full seasons.   For the years involved in the test, Crecy Lake received comparable fall plantings of fin-clipped underyearling trout.

The late opening resulted in a much greater catch of trout in June, not only from more fishing effort, but also from a better catch per unit effort, than experienced in the other two years at that season.   However, only a moderate improvement in catch continued into July.   Adverse effects of high water temperature on feeding and food consumption, and previous removal of trout by anglers are advanced as the most important factors determining the poor angling success in July and August.

There was a poorer survival of planted trout to the anglers' catches with the late opening of the fishing season. This result detracted from the improvement in early summer angling.

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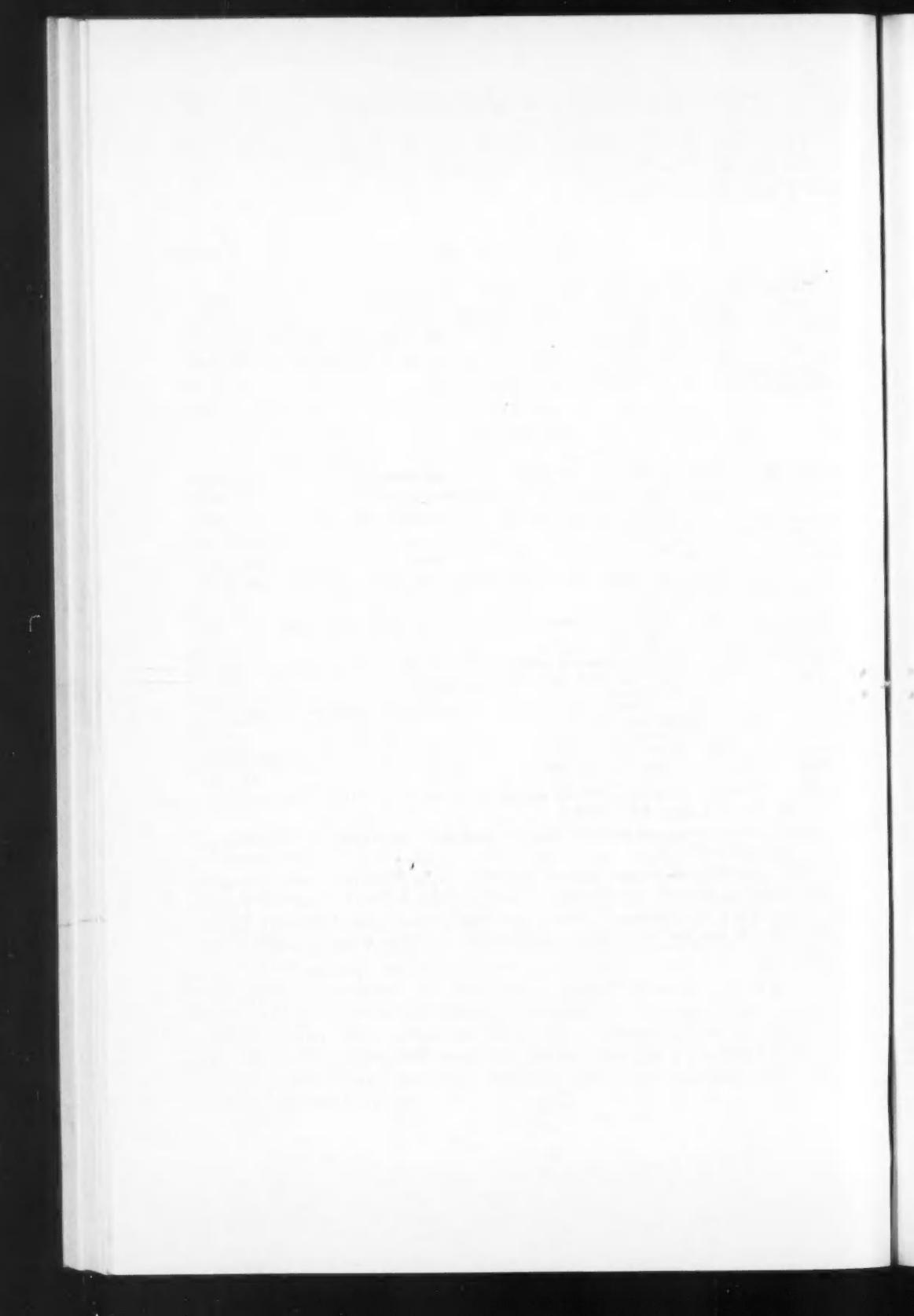
An Aquarium for Maintaining Constant Prey Population Densities in Studies of Predator–Prey Interactions[1]

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ABSTRACT

An adjustable aquarium is described and illustrated. The apparatus provides a means of regulating the effective volume of a tank in relation to variations in prey population.

INTRODUCTION

A METHOD of maintaining constant prey population densities was needed for studies at the Belleville Institute on the population interactions of predacious aquatic organisms and their prey, *Daphnia pulex* (de Geer). It was desirable to measure the capacity of the predators for prey under conditions of constant prey densities. To counteract the reduction in prey density caused by the feeding of the predators two methods suggested themselves: the constant addition of prey, which proved impractical; and the reduction of the experimental environs. An adjustable aquarium was devised consisting essentially of a transparent plastic tank and a moveable screened partition. As the partition was moved forward water escaped through it but organisms were restricted at one end. The following is a description of the aquarium.

DESCRIPTION OF APPARATUS

The apparatus (Fig. 1) has three main components: a tank, a moveable partition, and a screw feed mechanism. It is mounted on a base 82 inches long. The tank (A) is of ½-inch transparent Perspex (Anthony Foster & Sons, Ltd., Church Street, Toronto, Ontario) and measures 12 by 12 by 42 inches inside. Its corner joints are cemented with ethylene chloride and bolted. The top edges are reinforced with angle aluminum (B) ⅛ by 1 inch, bolted to the Perspex. Perspex fillets (C) ⅛-inch square are cemented to two inside bottom corners of the tank. These prevent the escape of organisms at corners that are otherwise difficult to seal with the partition gasket (E).

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[1] Received for publication June 13, 1960.

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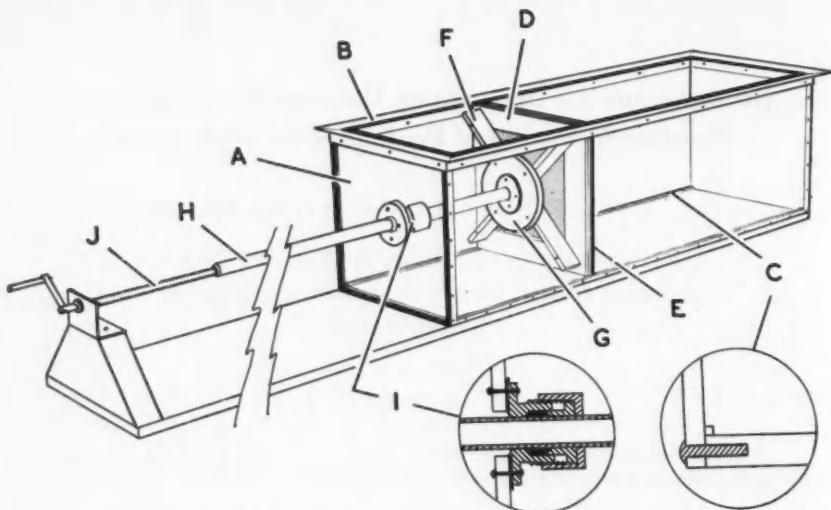
FIG. 1.   Drawing of aquarium and its components.

The moveable partition (D) is of two pieces of $\frac{1}{4}$-inch Perspex each having an 8-inch-square centre section removed. These are cemented together with a piece of 80-mesh nylon screen sandwiched between. A gasket of wool pile weatherstrip (E) is fastened to the side and bottom edges of the partition. The partition (D), Perspex cross-arms (F), and a 6-inch diameter Perspex disc (G) are bolted together and fastened to the screw feed mechanism.

The screw feed mechanism consists of a tubular plunger (H), a packing-gland (I), and a feed screw (J). The plunger is a thin-walled brass tube 1 inch in diameter and $39\frac{1}{2}$ inches long with a flange soldered on one end and a short threaded sleeve fastened in the other to serve as a nut for the feed screw (J). The brass packing-gland (I) is packed with cotton string and bolted to the tank through a rubber washer. Water leakage is prevented by tightening the packing-gland nut to squeeze the packing against the plunger. The feed screw (J) is a $\frac{1}{2}$-inch diameter steel rod with $37\frac{1}{2}$ inches of thread. One end is threaded into the end of the plunger (H). The other end is fitted with a crank and held in a fixed position on a bracket by metal collars. As the crank is turned anti-clockwise the plunger and partition are moved forward, thus reducing the effective volume of the tank from a maximum of 3 cubic feet to zero. The volume is calibrated on the angle aluminum (B).

Underwater Television Observations of the Swimming Speed and Behaviour of Captive Herring[1,2]

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ABSTRACT

The behaviour of groups of freshly caught herring in a cage at sea was observed by underwater television. Flight reactions occurred when the main engines of the supporting boat were started. When lowered in the water at about 0.3 ft (9 cm) per second, the herring descended by sinking while swimming horizontally. At 100 ft (30 m) herring which had been lowered from the surface swam normally and responded to currents under artificial light. They rose towards the surface by swimming vertically. Herring responded to real and apparent currents greater than 0.1 to 0.3 ft/sec (3–9 cm/sec) by swimming upstream at a rate in excess of the current speed, until their maximum swimming speed had nearly been reached. Maximum swimming speed varied from 3.0 ft/sec (91 cm/sec) for groups of mean length 15.2 cm (6 in) to 4.7 ft/sec (143 cm/sec) for fish 26.7 cm (10.5 in) mean length (end of head to longer lobe of the extended tail). This maximum swimming speed is the greatest speed that 50% of the fish group could maintain for 1 minute after swimming for 9 to 30 minutes at the rate shown by excited fish.

INTRODUCTION

MANY PROBLEMS inherent in the laboratory investigation of herring behaviour were overcome by testing freshly caught herring in a cage at sea. In particular, it was difficult in the laboratory to produce linear currents in a large enough volume of water to study the behaviour of groups of herring in currents and to determine their maximum swimming speeds. Nor was it possible without special equipment to duplicate the pressure changes encountered by the fish when moving from the surface to depths of 100 ft (30 m) and still keep the fish groups under observation. At sea, water passing through a cage as it was towed provided a linear current of large dimensions and changes in pressure were easily produced by lowering the cage. The resulting changes in the behaviour of herring were observed by means of underwater television.

Herring in nature have been reported by several observers to orientate upstream when in a current. Balls (1951) noticed that young North Sea herring usually stemmed currents. Huntsman (1953) concluded that herring in the Passamaquoddy region head and swim upstream when in a current and close to the bottom. Jones (1957) followed the movements of a herring school off the French coast at 5 to 10 fathoms (9–18 m) over a bottom at 14 fathoms (26 m)

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by echo sounder.   His observations suggested that the herring were being carried with the current over the ground but were swimming into it at a rate of 1 to 2 knots (0.5–1.0 m/sec).   Moore (1898) after observing herring in the Passama-quoddy region reported that he had never seen any evidence that herring feeding at the surface keep facing the current.   If their food drifted with the current then he found that the fish also drifted; if the food organisms stemmed the tide the fish followed them.

Although there appears to be a discrepancy between Moore's results and the others this may be due to two reasons.   Firstly, the herring observed by Moore were close to the surface and may have been a long distance from any fixed objects, such as the bottom, which would provide the visual reference points on which a current response could be based.   Secondly, the herring were feeding and our observations have shown that captive herring in a pen communicating with the sea lost their orientation into the current when feeding.   As food drew near, these fish ceased to swim into the current and drifted downstream for a foot or two beside the food before bending the tail and springing forward to seize it.   As soon as the food was taken the fish again responded to the current and swam upstream to its former position.

If herring swim against the current the effectiveness of their response will depend on their swimming speed compared with the current speed.   Fredriksson and Aasen (1950) found that large herring taken off the Norwegian coast, near Bergen and held undisturbed in live nets swam constantly in an anticlockwise direction at a speed of about 6 to 8 metres a minute (0.3–0.4 ft/sec).   Jones (1957) suggested that a school of herring off the French coast were swimming against the current at 1 to 2 knots (1.7–3.4 ft/sec).   Recently the maximum swimming speed of herring has been determined by Blaxter and Dickson (1959) using captive fish taken near Aberdeen, Scotland, which were tested singly by various methods. Taking figures from their graph, the swimming speed varied from about 3.5 ft/sec (1.1 m/sec) for 16 cm (6.3 in) herring to 5 ft/sec (1.5 m/sec) for 26 cm (10.2 in) fish.   There is close agreement between these results and the figures for maximum swimming speed maintained for one minute for groups of herring of these sizes obtained in the present study.

TELEVISION CRUISES

Two cruises using underwater television were made during 1958.   The first, from May 16 to May 28, used television equipment belonging to the United States Bureau of Commercial Fisheries, Woods Hole, supervised by Mr R. Livingstone.   The second, from September 18 to October 1, used the National Research Council of Canada's unit developed by Mr W. M. Cameron.

EQUIPMENT

Two boats from the Biological Station, St. Andrews were used, M. V. *Harengus* to carry the television equipment and M. B. *Mallotus* with stock tanks for the herring.

A cage 6 ft long, 4 ft wide and 4 ft deep ($1.8 \times 1.2 \times 1.2$ m), covered with 1-inch mesh cotton netting held the herring during observation (Fig. 1). At one end of the cage the television camera was attached with its lens in the centre of

CURRENT METER   TELEVISION CAMERA

STREAMER   I FOOT   CAGE
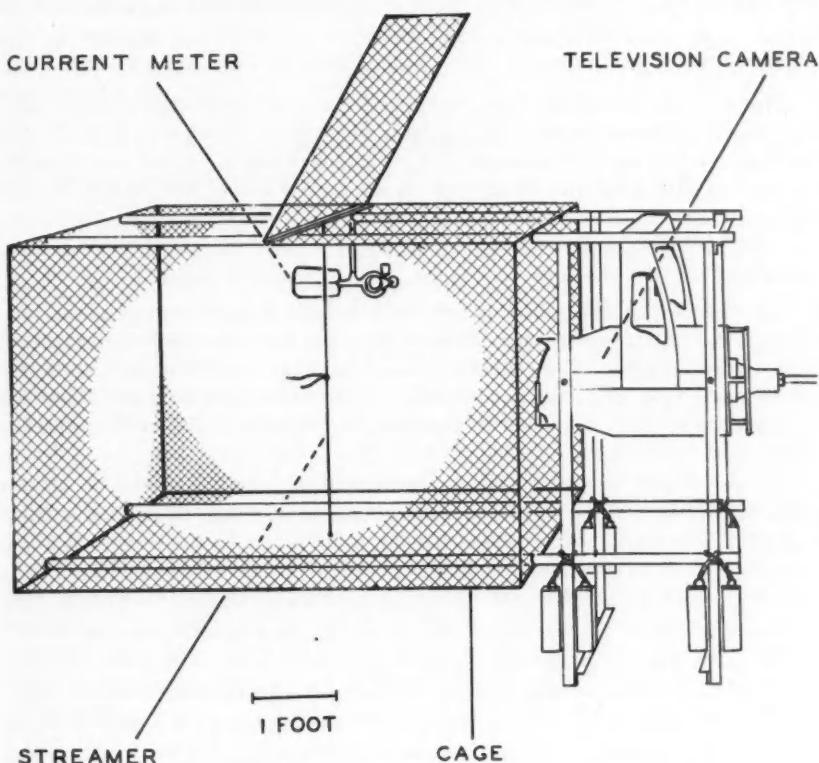
Fig. 1. Cage and camera used during the second television cruise.

the end wall so that a picture of most of the interior of the cage could be seen on a monitor screen on board the vessel. Both cameras were cylindrical, with diameters of 10 and $14\frac{1}{2}$ inches respectively (254 and 368 mm). The unit was slung from booms on M. V. *Harengus* so that when it was towed the camera always moved first through the water with its long axis parallel to the flow. Thus fish swimming into the apparent current faced the camera.

A Gurley current meter was suspended inside the cage, half way back and 10 inches from the top. A small streamer of white string in the centre of the cage where it was easily seen on the television screen gave visual indication of the direction of minor currents through the cage. When observations on the behaviour at depths made it necessary, a lamp with a No. 1 photoflood bulb rated at 8500 lumens was mounted on top of the camera and directed to shine

obliquely downwards into the cage. Most observations were made at 20 ft (6.1 m) where natural illumination was sufficient to give a clear picture of the herring in all parts of the cage.

METHODS

HANDLING HERRING

Herring were obtained every morning from weirs in Passamaquoddy Bay. They were transferred to the carrying tank and later to the cage in tubs of water which were immersed to release the fish. Groups of herring to be tested usually consisted of about 50 fish, though as many as 200 were used during the first cruise.

EXPERIMENTAL PROCEDURES

To observe the behaviour of herring groups in natural currents, the boat was anchored in a tidal flow, herring were placed in the cage and lowered to 20 ft where they were clear of the hull. Detailed records of herring behaviour and current speed were kept for each minute. The results were later supplemented by direct observation of herring in the same cage buoyed and tied to a wharf in a tidal current.

To determine the maximum swimming speed and behaviour at greater speeds than observed in natural currents, groups of less than 50 herring selected by eye to be as nearly of one size as possible were placed in the cage, which was lowered to 20 ft. After being held for 15 minutes, the cage was towed at a gradually increased speed until all the herring were swept onto the back of the cage. A record was kept of the number of herring on the back mesh at the end of each minute. The herring were counted and measured after each determination. From this information it was possible to calculate the current speed at which 50% of a herring group of known mean length failed to keep pace with the cage. The water temperature at 20 ft was taken before and after each test. New fish were used for each determination.

The apparatus was also used to determine the behaviour of herring at various depths down to 100 ft.

CALIBRATION OF CURRENT METER

As the current meter was placed near the top of the cage away from the fish it was necessary to calibrate it in terms of the water flow past the fish. After the cruises were over a second current meter was mounted in the cage 10 inches (25 cm) from the bottom and in three positions in the area occupied by the fish during the experiment. Two of the positions were on the mid-line at $1\frac{1}{2}$ and 3 ft (46 and 91 cm) from the front end, and the other was $1\frac{1}{2}$ ft (46 cm) back and 1 ft (30 cm) from the side. Simultaneous readings of the original and second meter were taken over the range of current speeds used in the experiments. The results obtained from the three positions were used to construct a graph from

which the current velocities recorded by the original meter could be expressed in terms of the rate of water movement past the fish. This corrected current speed was used when calculating the maximum swimming speed of the herring. Over the range of maximum swimming speed (3–4.7 ft/sec, 91–143 cm/sec) there was an average discrepancy of 0.2 ft/sec (6.1 cm/sec) between the calibration curve and the recorded bottom speeds. No correction has been applied to speeds below 1 ft/sec.

HERRING BEHAVIOUR

RESPONSE TO VIBRATION

Herring held in the cage at 20 ft showed a well marked flight reaction to tugs on the supporting rope. The herring formed a dense school and swam rapidly from one side of the cage to the other.

No flight response was obtained when M. B. *Mallotus* with a 100 h.p. Cummins engine approached from a distance and on successive runs passed at 20, 10, 5 and 2 ft away from the rope to the cage. The engines on the supporting boat M. V. *Harengus*, were then started. M. V. *Harengus* is equipped with two D-17000 Caterpillar marine engines with a starting motor of 27 h.p. On one of two occasions, the herring showed the flight response to the starting motor. The herring responded to the starting of the main engines on one occasion by forming a dense school, increasing their rate of swimming and losing their orientation into the current. On the second occasion the herring momentarily stopped swimming and sank to the bottom, then quickly resumed their orientation into the slight current. This response is similar to the fishermen's report that herring enclosed by a net may, if startled, suddenly sink to the bottom. As M. V. *Harengus* was supporting the cage during these tests the vibrations from the engine may have reached the fish through the hull or indirectly through the rope to the cage.

BEHAVIOUR IN CURRENTS

In natural currents greater than 0.1–0.3 ft/sec (3–9 cm/sec), the herring remained in the upstream half of the cage, usually within a foot of the bottom. There they swam continuously from one side wall to the other, appearing at the lowest current speeds to be swimming directly across the current though as they kept a constant distance from the front mesh there must have been a slight component of their path in the upstream direction to compensate for the current. The response to currents was most clearly seen when the herring reached the side wall where they always turned upstream before swimming across the cage again. At low current speeds the cage did not always swing to bring the camera end upstream. However, the direction of the current could be judged by the position of the streamer and it was found that the herring's response was always related to the current despite differences in the direction of the water flow through the cage.

When there was no flow of water through the cage or its speed was less than 0.1–0.3 ft/sec necessary to elicit the response, the herring followed the walls of the cage, sometimes turning back at a corner, but usually turning to follow the next wall.

Towing the cage caused water to flow through the front (camera) end. The herring responded to this apparent current exactly as they responded to natural currents of the same velocity. This permitted investigation of the response of the herring to higher current velocities than had been encountered in the tidal flow. As the speed of the current increased, the length of the movements across the cage decreased. The herring as they swam from side to side inclined their bodies so that the head faced partly upstream and this upstream inclination became more pronounced as the current velocity increased. As the current increased still further a point was reached for each fish at which it was facing directly upstream and only deviating occasionally by a few inches from a straight path. A further increase in speed caused these fish to be forced backwards, tail-first and still swimming vigorously upstream until they were carried against the back of the cage.

The existence of side to side deviations in the path of the fish showed the herring were swimming at a faster rate than the current until their maximum swimming speed had almost been reached. Herring at the back of the cage when towing started used this excess swimming over current speed to come to the front of the cage. There further progress in the upstream direction was prevented by the front mesh of the cage and the side to side movements began. Herring never swam from side to side in the downstream half of the cage, showing that these movements across the current were due solely to the presence of a barrier to movement upstream. In nature where there is no barrier to movement it is expected that herring near the bottom and in a current would continue to swim upstream at a rate greater than the current speed until near their maximum swimming speed.

The Stimulus Necessary for the Response to Currents

As the herring behaved in the same way in natural currents and in the apparent current produced by towing the cage they must have been basing their response on stimuli from the cage, the only common factor in the two situations. This stimulus could not be a tactile one as herring showing the current response did not touch the cage. The stimulus could have been a visual one or perhaps some change in the characteristics of the water streaming through the meshes to the fish, such as an odour or the presence of turbulence. The likelihood that the response was based on visual stimuli was strengthened when it was observed on two different occasions that a decrease in visual stimuli from the cage was followed by a failure of the response to current although all other stimuli were still present. A group of herring lowered to 100 ft, where the natural light intensity was too low for observation, swam normally, schooled and responded to currents under artificial light. The current entered the cage through the right-hand

corner of the cage and the herring consistently oriented into it and not to the light which was mounted above the camera. The light was switched off for 5 to 10 sec on several occasions. When it was turned on again the herring were seen to be further downstream and motionless. Immediately they began to swim and advanced upstream to group again in the right-hand corner of the cage. These observations were few and could not be repeated because the camera case leaked at these depths but they suggest that visual stimuli are important. The short period of darkness gave little time for light adaption so these observations cannot be interpreted to mean that light intensity at 100 ft during the day is too low for visual orientation into a current.

On a second occasion a group of herring were being towed in the cage at 20 ft. The speed had increased until 4 out of 104 fish failed to keep pace and then was decreased. One minute elapsed at the decreased speed during which no more fish were swept backwards. Then there was a sudden change in the water from clear to very muddy. Large numbers of herring lost their position in the upstream part of the cage and later 66 were found to have struck the back mesh although the speed was all the time decreasing. The herring did not turn away from the dirt-laden water but were displaced downstream tail first suggesting that the loss of their upstream position was caused by the obscuring of visual reference points, not an avoiding action by the fish.

Behaviour at Various Depths

As the cage was lowered from the surface to various depths the herring kept pace with it mainly, if not wholly, by sinking. Thus herring being lowered to 100 ft (30 m) at a rate of 0.3 ft/sec (9 cm/sec) were at all levels in the cage, usually swimming horizontally but with occasional short excursions up and down. At a greater rate of descent, 0.6 ft/sec (18 cm/sec), the herring rose to the top of the cage. They were never seen to hold the head downwards and swim towards the bottom.

In contrast, the herring ascended by swimming upwards and were able to swim directly towards the surface with their bodies held vertically. They kept close to the upper mesh and responded to the flow of water through it as they did to a horizontal water flow.

At all depths between the surface and 100 ft, the greatest depth which could be reached with this equipment, herring accustomed to surface pressure swam normally, and responded to currents when sufficient light was present. Typically at 20 ft during the day herring remained in the lower half of the cage, while at 40, 60 and 100 ft they occurred at all levels in the cage.

Maximum Swimming Speed

The television and cage unit was used to determine the maximum speed that recently caught herring could maintain for one minute. Groups of 50 or less, similar-sized fish in the cage were towed at a gradually increased speed until

all the fish failed to keep pace with the cage. At speeds below the maximum swimming speed, as described previously under the behaviour in currents, the fish were swimming at a speed greater than the water velocity through the cage, this excess speed expressing itself in movements from side to side across the water flow. Thus during this period the fish were determining their own swimming speed which was neither the towing speed nor their maximum swimming speed but which may be considered to be the speed of herring excited by strange surroundings, vibrations, the handling procedure and the movements of water through the cage. The maximum swimming speed determined under these conditions was thus the greatest speed that the herring could swim for one minute after swimming for 9 to 30 minutes at the rate shown by excited fish.

The average current velocity and the number of fish at the end of each minute which had failed to keep pace with the cage were recorded. After each determination the cage was hauled and the fish counted and measured from tip of snout to the end of the longest lobe of the extended tail. From these data the greatest speed that 50% of the fish group of known mean length could maintain for one minute was calculated and taken as the maximum swimming speed.

The speed at which 25%, 50% and 75% of the fish failed is given in Table I.

TABLE I. Details and results of experiments to determine the maximum swimming speed of herring.

Date and expt. No.	Number of fish	Mean length	Size range	Hours after capture	Temper- ature	Average increase in speed	Time to 50% failure	Current speed at which fish failed**		
								25%	50%	75%
1958	no.	cm	cm		°C	ft/sec/min	min	ft/sec	ft/sec	ft/sec
Sept. 26(4)	31	15.2	12.2–17.5	7¾	12.2	0.16*	9	2.8	3.0	3.2
Sept. 26(2)	50	18.5	15.5–21.5	3¾	12.1	0.10	25	3.8	4.0	4.1
Sept. 26(5)	43	18.5	15.9–21.1	9	12.4	0.11	12	2.5	3.1	3.1
Sept. 29(3)	35	20.7	18.7–23.3	6	11.7	0.12	18	2.9	4.0	4.1
Sept. 26(3)	30	22.0	19.6–27.1	5¾	11.6	0.11	24	3.3	3.7	4.0
Sept. 30(1)	46	25.8	23.5–29.3	1¾	11.7	0.11*	26	4.0	4.4	4.5
Sept. 29(2)	22	26.7	24.9–30.0	3¾	11.7	0.08	30	4.4	4.7	4.7

*To 75% failure.   Unstarred entries to 100% failure.
**2.5 to 4.7 ft/sec equals 1.6 to 2.8 knots.

In the second and third horizontal columns of this table results have been given for two groups of herring of the same mean length and of the same stock which were tested at the beginning and end of the day. Strong winds at the end of the day, making handling difficult and necessitating a short period of towing to a speed of 2 ft/sec before the scheduled tow, rather than the increased time since capture, are likely to be the cause of the difference in swimming speed between the two groups.

The results in the table have been arranged according to the mean length of the fish. When treated statistically there was found to be a positive cor- relation ($r = +0.90$; 5 df) significant at the 1% probability level between mean length and the maximum swimming speed; that is, the larger herring overcame higher current velocities before 50% failed.

DISCUSSION

The results obtained during these cruises when applied to wild fish, suggest that herring near the bottom or any object which gives a fixed visual reference point will move upstream in a current. Conversely, herring far from the bottom or at very low light intensities will not have their direction of swimming determined by the current although they will be displaced downstream by it. If herring schools far from the bottom were swimming randomly in direction, an increasing number of schools would be moved downstream in a given time as the current increased until, when the current exceeded the normal swimming speed, all the schools would be displaced downstream. Even when herring are responding to the current if the current speed exceeds their maximum swimming speed they will be moved downstream. For herring up to 26.7 cm (10.5 in) any current which exceeds 4 ft/sec (1.43 m/sec) will carry all the herring with it. A current of 3 ft/sec (9 cm/sec) would be sufficient to displace downstream all herring less than 15.2 cm (6.0 in) long.

The descent of herring from the surface appeared to be due mainly, if not wholly, to sinking. For the descent to be made rapidly, the herring initially would have to be quite dense compared with sea water but once the descent had begun it would be accelerated as the increase in pressure reduced the volume of gas in the swim bladder and the buoyancy of the fish. Magnan (1929) reported a "sinking factor" of 1034 for the herring, which is high according to Jones and Marshall (1953) as marine fish with a swim bladder usually have a factor of 980 to 1013. The sinking factor is numerically equal to 1000 times the quotient obtained by dividing the density of the animal by that of its environment (Lowndes, 1937).

ACKNOWLEDGMENTS

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Seasonal and Diurnal Vertical Distribution of Herring (*Clupea harengus* L.) in Passamaquoddy, Bay, N.B.[1,2]

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ABSTRACT

The depth of schools of immature herring in Passamaquoddy Bay was determined from echo-sounder records taken from 1947 to 1958. The records gave no information on the presence of herring between the surface and 14 ft, and any herring in this zone have been omitted from the calculations. The herring schools showed diurnal vertical movements, being closer to the surface by night than by day in every month of the year. From May until December the median depth varied from 30 to 44 ft by day and from 21 to 26 ft by night. From January to April the schools were deeper in the water by day with a median depth of 83 to 126 ft, though still rising towards the surface at night, to a median depth of 36 ft in February. No correlation was found between the mean solar radiation for the daylight hours and the median depth of herring by day in each month. Between 2° and 4–7°C there was a significant inverse correlation between water temperature and the depth of the herring by day, but as temperature increased above 7°C, up to 12°, there was no further decrease in median depth.

INTRODUCTION

UNDER THE AUSPICES of the International Passamaquoddy Fisheries Board, a study was made of the vertical distribution of herring in Passamaquoddy Bay. This study formed part of a wider investigation to determine the effects of a tidal power installation on the fisheries of the area. Under the proposed power project Passamaquoddy Bay would be separated from the sea by dams, but sea water from the Bay of Fundy would still be able to enter the Bay through filling gates during the flood tide. Obviously, the continued success of the fishery for immature herring, which is based on fish entering the area from outside, depends in part on the vertical distribution of the fish compared with the vertical extent of the filling gates. A knowledge of the vertical distribution of herring in Passamaquoddy Bay was also needed to determine how a warmer and less saline upper water layer during the summer might affect the herring population. The depth distribution of herring was obtained from an analysis of the depth of fish traces on echo-sounder records taken in the area.

Diurnal changes in depth are a well-known feature of the behaviour of herring shoals on both sides of the Atlantic. In the North Sea, it appears that the upward movement at night is more extensive among small immature herring than in the large herring (Lucas, 1936). Richardson (1952) followed the movements of herring shoals in the North Sea by echo-sounder and found there was a correlation between light penetration and the depth of the top of the herring shoals. In the North Shield fishery the herring were deepest in the water by day, averaging 144 ft (44 m) from the top of the shoals to the surface, and

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rose towards the surface at night to an average depth of 94 ft (29 m). Richardson also found that a thermocline did not restrict the herring shoals in the course of their diurnal movements.

For the Passamaquoddy Bay region, Moore (1898) records that all but the "brit" (herring 5–10 cm or 2.0–3.9 inches long) are in deep water and offshore during the day and approach the surface at night. He also remarks that during the winter the herring apparently stay in deep water. Johnson (1939) gives the vertical distribution of herring in the top 10 ft (3 m) of water in the Passamaquoddy region. His results are of special value in supplementing the present investigation as they fix the upper limit of the herring's distribution when this falls in the upper 10 ft, a zone which was not recorded on our echo sounders. Johnson's results only cover the months from June to September and many of the observations were made on fish confined in weirs. He showed for these months that herring of the sizes found in Passamaquoddy Bay occur in the upper 10 ft at sunrise and sunset, and, if the sky were overcast, for several hours before sunset and after sunrise. In direct sunlight at midday only herring of 8–10 cm (3.1–3.9 in) occur in this zone; herring from 14 cm upwards have their upper limit at 10 ft or deeper. On moonlight or starlight nights herring of all sizes were seen breaking the surface.

PHYSICAL CHARACTERISTICS OF PASSAMAQUODDY BAY

Passamaquoddy Bay is an inlet of the sea at the southwestern end of the Bay of Fundy. At high tide the Bay, excluding the St. Croix estuary, has an area of 80 square statute miles (207 sq km). The depth is less than 200 ft (61 m) except in the vicinity of the passages which link Passamaquoddy Bay with the Bay of Fundy. Water temperature at 30 m (98 ft) from 1947 to 1958, the period of this survey, reached a maximum in September and a minimum in February or March. Salinities reached a maximum in October and a minimum in April or May. During the year the temperature and salinity of the surface layers of Passamaquoddy Bay vary from about 0° to 14°C and from 24 to 32‰. The temperature of deep water varies from 1° to 12°C and its salinity from 31 to 33‰ (Trites, 1959).

HERRING POPULATIONS

Herring occur throughout the year in Passamaquoddy Bay, supporting a weir fishery from May until October and providing occasional catches to seiners during the rest of the year. The fishery is based on immature fish and there is no evidence that mature herring spawn in the area. Occasionally groups of herring less than 9 cm (3.5 in) long are seen in the weirs or are entangled in fishing gear. Fish of this size slip through the meshes of the net when weirs are being seined but, with this exception, samples from the weir catches can be taken to represent the size of herring present in the Bay. Samples taken from 1957 to 1959 showed an interquartile range of overall length (tip of head to longest point on the closed tail) of 8.8–11.0 cm (3.5–4.3 in) in April. The herring caught

increased in length throughout the summer until November the interquartile range was from 18.2 to 20.8 cm (7.2–8.2 in) in the fish sampled (Table I). No samples were available for December to March from Passamaquoddy Bay.

TABLE I. Interquartile range in overall length (tip of head to longest point on closed tail) of herring in samples from weir, seine, and trawl catches in Passamaquoddy Bay in 1957, 1958 and 1959.

Month	Lower quartile	Upper quartile	Total number fish sampled	Number of samples
	cm	cm		
April	8.8	11.0	380	1
May	10.2	14.3	2,122	8
June	15.4	16.8	472	2
July	14.8	17.2	3,053	13
August	14.1	18.6	800	3
September	16.7	20.0	1,610	10
October	14.1	18.5	345	4
November	18.2	20.8	184	1

METHODS AND MATERIAL

ECHO-SOUNDER RECORDS

Echo-sounder records from Bendix super-sonic depth sounders were examined for the presence of fish traces. These records were taken in Passamaquoddy Bay over the years 1947 to 1958. As information was taken from records made for other purposes there was an unequal coverage of day and night hours and of the various months with more records for the daylight hours and the summer and autumn months when boat work was at its peak. The number of squares in the grid on the echo-sounder paper which contained fish traces are shown in Table II for each month.

TABLE II. Number of squares of echo-sounder record containing traces of fish which were used for the determination of the depth distribution of herring.

Month	Day	Sunset	Night	Sunrise	Total
January	60	18	–	–	78
February	10	–	106	–	116
March	126	14	–	10	150
April	65	–	–	–	65
May	1,218	28	27	2	1,275
June	1,589	14	–	52	1,655
July	2,275	79	319	70	2,743
August	1,589	261	572	–	2,422
September	2,533	203	119	317	3,172
October	190	141	510	–	841
November	466	427	–	238	1,131
December	87	38	362	–	487

INTERPRETATION OF TRACES

The records were examined for the presence of traces from 10 ft below the transducer to the bottom. Traces were assumed to be due to turbulence and discarded if they occurred only in the upper 30 ft and continued upward until they were lost in the 0 to 10 ft zone, giving a triangular shape with the base upwards. Traces were most likely to be due to turbulence if they occurred over an irregular bottom or near the passages to Passamaquoddy Bay. All dubious traces were omitted. It was assumed that most of the remaining traces were caused by herring as this is the only schooling fish present in quantity in Passamaquoddy Bay. The average annual landings from 1937 to 1958 in the area show that the herring landings are about 75 times greater by weight than all other fish. Small pollock, which are not caught commercially, can be seen round wharves and weirs and may have been the cause of some of the traces.

For March, May, July, August and November, a total of 17 records of simultaneous fishing and echo sounding were available to confirm that herring were present in the same area as the fish traces.

Mr B. B. Parrish, in charge of herring investigations at the Marine Laboratory, Aberdeen, examined typical traces from Passamaquoddy Bay and found them similar to herring traces recorded round the coasts of Great Britain.

ANALYSIS OF RECORDS

The recording paper from the echo sounders bore a grid which, on the 0 to 200 ft scale used, divided the water column vertically into 10 ft intervals and horizontally into 1 minute intervals. At the usual cruising speed of the boat from which most of the records were obtained, the horizontal divisions of 1 minute would correspond to a distance of 912 ft (278 m).

The records were divided into sections in which fish traces were present. For single fish traces these sections were only 1 minute wide but where groups of fish occurred, one section was made to cover the whole group even though this included some minutes in which there were no fish traces. By this means the absence of fish was only accorded significance when it occurred close to water which contained fish and the large areas devoid of fish were removed from further consideration. The sections were further arranged so that each fell inside a 1 hour period and the results were recorded according to the hour and month.

In each section a count was made of the number of squares 1 minute wide and 10 ft deep representing the amount of water which occurred in each 10 ft zone. As the record went down to 200 ft and most of Passamaquoddy Bay is shallower than this there was usually a decreasing number of squares with

depth.   For the same section a count was made of the number of squares in each
depth zone in which there were fish traces.   No account was taken of the size
of the fish trace in each square but as large traces commonly occupied more than
one square they gave a higher count.   Notes were made on the size, appearance
and distance from the bottom of the traces.

When analysis of the records was to be on an hour to hour basis all the
results relating to the same hour in the month were first added together.   To
bring out the diurnal changes in depth more clearly the day was sometimes
divided into four periods, day, sunset, night and sunrise, and all the results within
each period were summed before being treated further.   The sunrise and sunset
periods included a full hour on either side of the predicted times of sunrise and
sunset in each month.   The remaining hours were assigned to the day or night
periods.

Data were recorded in two ways; as the depth distribution of squares
containing fish traces, and as the percentage of squares showing fish at each
depth expressed as a percentage of all the squares showing fish.   The former
unweighted analysis of the data gives the actual distribution of fish recorded in
Passamaquoddy Bay.   Weighting the data by the latter method compensates
for the decreasing volume of water with depth so that the results are more
generally applicable.   Median depths and the upper and lower quartiles were
determined by linear interpolation.

On the Bendix sounder records, zero on the depth scale indicates the level
of the transducer cone.   Most records came from M.B. *Mallotus* and M.V.
Harengus which have the transducer 3 and 5 ft below the water line respectively.
A few records came from M.V. *Gulf Explorer* and *J. J. Cowie*, which have trans-
ducer depths of 3 and 5 ft.   To compensate for the depth of the transducer below
the surface, 4 ft (1.2 m) has been added to the calculated depth of the herring
schools.   In all the calculations any herring groups which lay between the
surface and 14 ft (4.3 m) have had to be omitted as they were not recorded by
the echo sounders.

RESULTS

Diurnal Vertical Distribution

A well-defined diurnal change in depth distribution was shown by herring in
Passamaquoddy Bay.   From the graph of median depth of fish shoals for each
month shown in Fig. 1, it can be seen that the herring are deeper in the water by
day, rise at dusk, are nearer the surface by night and descend at dawn.   Figure
2 shows the hourly distribution of fish in September, a month typical of the
May to December period, and in March, a month typical of the remainder of the
year.   In September the herring descend to their greatest depth 4 to 5 hours
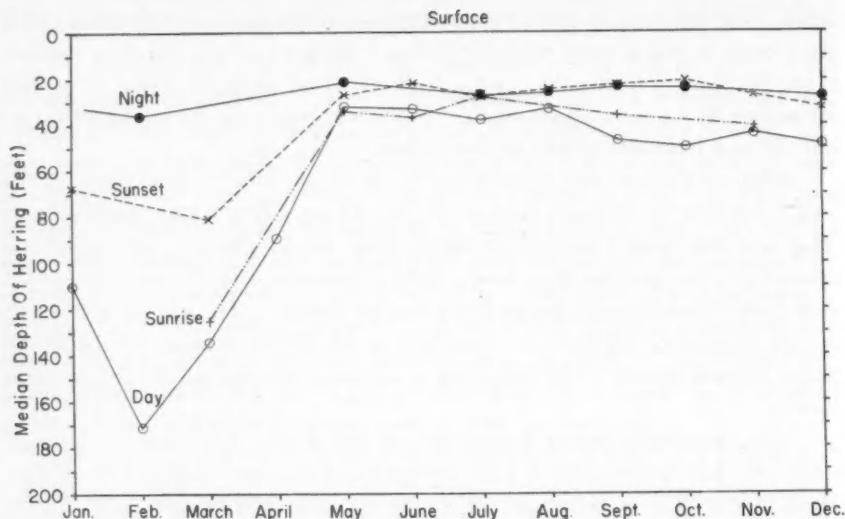
FIG. 1.   Median depth of herring in Passamaquoddy Bay at sunrise, day, sunset and night
throughout the year (weighted data).

after sunrise when the median depth is 60 ft (18.3 m).   During the day they
rise slowly, except for a second depression at 1200 and 1300 hours when the sun
is at its highest.   By 1800 hours, which is within one hour of sunset, the herring
are near the surface and remain there with minor fluctuations in depth until at
sunrise they begin to descend.   The median depth for the whole night calculated
from the sounder records was 24 ft (7.3 m), but it was obvious when studying the
records that the fish extended upwards into the 0 to 14 ft zone where they were not
recorded.   If the assumption is made for the night hours in September that there
are as many fish in the upper 14 ft as in the 10 ft zone immediately below it, then
the median depth would be 19 ft instead of 24 ft (5.8 instead of 7.3 m).

The record for March is incomplete but it shows that the greatest depth
during the daylight hours is reached 1 or 2 hours after sunrise.   The herring
then rise slowly in the water during the day but do not show a depression when
the sun is on the meridian.   The fish traces obtained during the day in March
were shown to be made by herring as simultaneous bottom trawling caught
about 20 lb (9 kg) of herring between 0920 and 1020 hours and 3,000 lb (1400 kg)
between 1115 and 1220 hours.   There are no night echo-sounder records for
March but in the previous month, February, when the fish are also very deep in
the water during the day, the herring rise in the water at night showing a median
depth of 36 ft (11 m).   In the months January to April inclusive the herring
undergo more extensive diurnal vertical migrations than in other months of the
year.
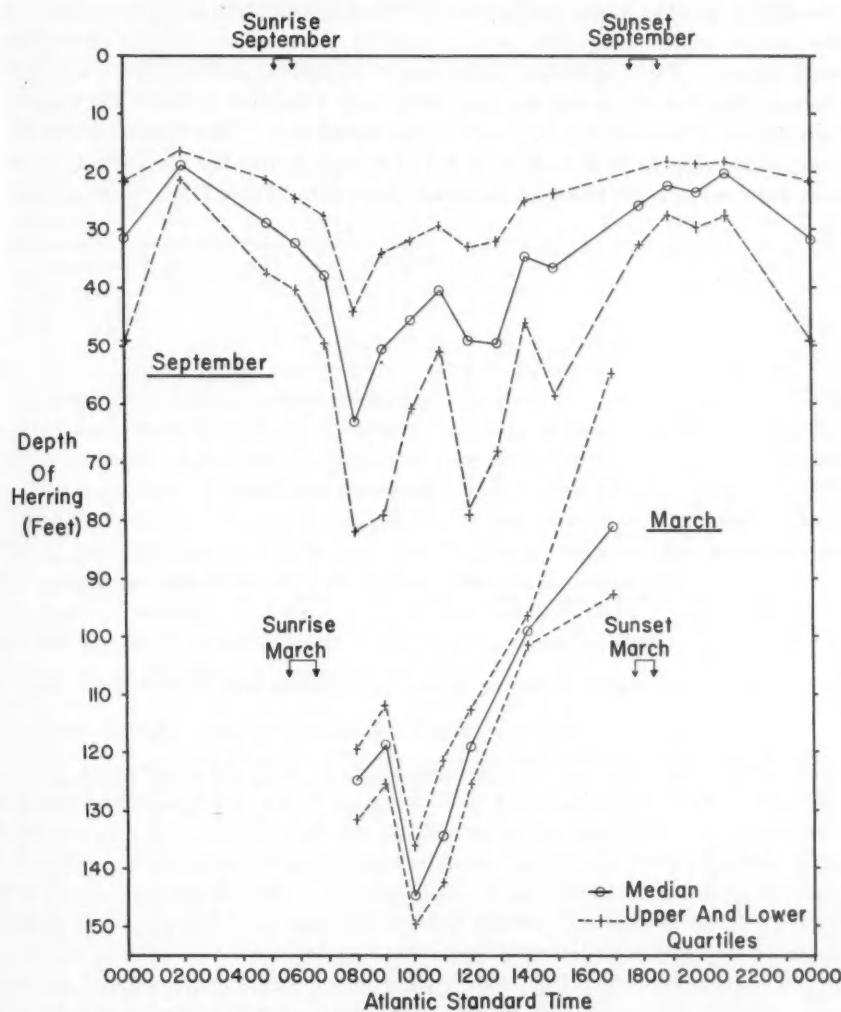
FIG. 2. The hourly depth distribution of herring in Passamaquoddy Bay in March and September (weighted data).

Seasonal Changes in Vertical Distribution

The discussion of diurnal changes in vertical distribution of the herring has already shown that a seasonal pattern of depth distribution is superimposed on the diurnal movements. This is illustrated by the seasonal changes in median depth shown in Fig. 1 and the detailed pattern of vertical distribution throughout the year shown in Fig. 3 and 4. From May until December inclusive the vertical distribution is very similar from one month to the next. The median depth for this period varies from 30 to 44 ft (9.2–13.4 m) during the day and from 21 to 26 ft (6.4–8.2 m) at night based on the unweighted data (Table III). Thus at least
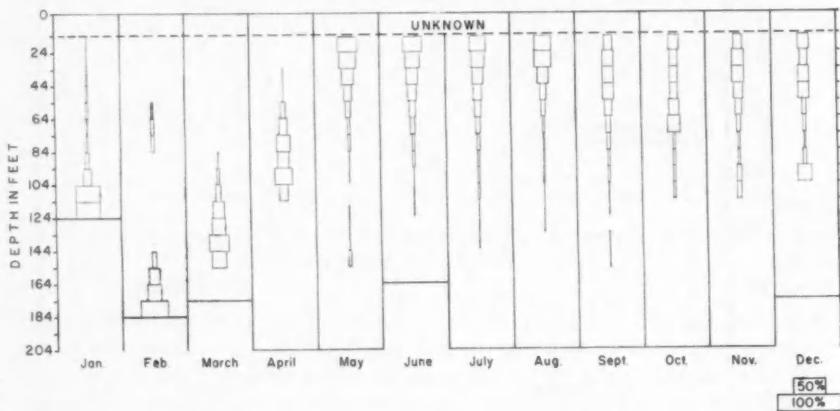

Fig. 3.   Vertical distribution of herring by day in Passamaquoddy Bay (weighted data).
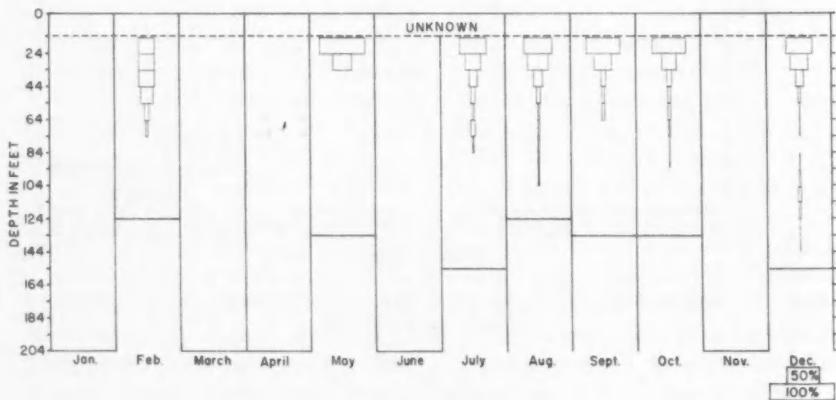

Fig. 4.   Vertical distribution of herring by night in Passamaquoddy Bay (weighted data).

TABLE III. Median depth in feet of herring in Passamaquoddy Bay (1 foot = 0.305 metre).

Month	Unweighted data				Weighted data			
	Day	Sunset	Night	Sunrise	Day	Sunset	Night	Sunrise
January	86	64	–	–	110	67	–	–
February	114	–	36	–	171	–	36	–
March	126	64	–	122	134	81	–	125
April	83	–	–	–	89	–	–	–
May	30	27	21	34	32	27	21	34
June	30	22	–	37	33	22	–	37
July	32	27	26	23	38	28	27	28
August	32	25	25	–	33	25	26	–
September	39	23	23	36	47	23	24	36
October	38	21	22	–	50	21	24	–
November	38	25	–	36	44	27	–	41
December	44	27	26	–	49	33	28	–

half of the herring population is always to be found within 44 ft of the surface and diurnal vertical movements are small. In contrast, from January to April the herring are much deeper in the water by day and as they rise at night to almost the same levels as at other times of the year their diurnal vertical movements are much greater. During these months the median depth by day varies from 83 to 126 ft (25–38 m). There are few records for the January to April period taken during the night, but as seiners can catch herring in these months, some of the fish must come within 50 ft (15 m) of the surface in the evening or at night while the boats are fishing. In February the median depth at night from echo-sounder records was 36 ft, which does not differ greatly from the depth of 21 to 26 ft calculated for the May to December period.

CHANGES IN THE FORM OF RECORDED HERRING SCHOOLS

In Passamaquoddy Bay herring schools which were recorded on the echo sounder seldom exceeded 230 ft in length or 30 ft in thickness (70 by 9 m). At night the schools broke up, first into smaller units and then more finely until the whole zone of the echo-sounder record occupied by the fish was peppered with small dots, presumably from individual fish. This change occurred $3\frac{1}{2}$ hr after sunset in August and September; $2\frac{1}{2}$ hr after sunset in November and 2 hr after sunset in December. A mid-water trawl fished at this time in November caught herring. Records taken just before dawn are few, but one for September shows the schools reforming half an hour before sunrise. It seems probable that the change in the nature of the trace at night is a reflection of the herring's inability to school visually with its neighbours below a certain light intensity. This has been observed in captive herring by Verheijen (1953) who records that with decreasing light intensity the shoal breaks up while feeding continues, then eating stops while obstacles are still avoided visually.

SOLAR RADIATION, TEMPERATURE AND MEDIAN DAYTIME DEPTH OF HERRING

Richardson (1952) found that there was a relationship between light intensity and the depth of the top of herring shoals by day in the North Sea. The present study, because it follows the changes in vertical distribution of immature herring throughout the year in the same locality, enables this relationship to be studied on a seasonal basis.

The data on herring distribution were collected over the period 1947 to 1958. Complete records of solar radiation at St. Andrews on the shore of Passamaquoddy Bay are only available for 1958 and 1959. However, an examination of the records of total sunshine recorded at Saint John Airport, 60 statute miles (97 km) away and 8 miles inland, shows that the differences in the mean monthly hours of sunshine between the 1947 to 1958 period and the 1958 to 1959 period are not significantly different ($t = 1.68$, df = 11). As the mean amount of sunshine in the 1958 to 1959 period was typical it is presumed that the mean solar radiation of these years is also typical of the 1947 to 1958 period. Of the total radiation recorded, only a fraction, given as between 0.5 and 0.35 by Strickland (1958), falls in the waveband 3800 to 7200Å which is slightly in excess of the range of visible light in a sunfish, *Lepomis* (Grundfest, 1932). Changes in the value of this fraction throughout the year would slightly increase the difference between summer and winter levels of radiation if only visible light were considered. There are no figures from which seasonal changes in light penetration into the sea may be derived.

In the upper panel of Fig. 5 the median depth of herring by day is plotted against mean solar radiation between sunrise and sunset for the corresponding month. No correlation significant at the 5% level of confidence was found between these two sets of data ($r = -0.11$, df = 10). Neither was a correlation at this level found between median daytime herring depth and the mean daily maximum solar radiation for each month ($r = -0.23$, df = 10).

In the lower panel of Fig. 5 the mean monthly water temperature at 30 m (98 ft) is plotted against median daytime herring depth. When temperatures above 7°C are considered, a correlation coefficient, r, of $+0.57$ is obtained which, with 4 degrees of freedom, is not significant at the 1% nor even at the 5% confidence level. Taking values for temperatures below 7°C gives a value of -0.93 for r which, with 4 degrees of freedom, indicates a correlation between temperatures and daytime herring depth at the 1% confidence level. The temperature of 7°C was arbitrarily chosen for these calculations. The graph suggests that daytime depth of herring ceases to be correlated with temperature somewhere in the range from 4 to 7°C. Any possible linking mechanism between low temperatures and the median depth of herring by day must be reconciled with the observation that at these same low temperatures by night the herring approach the surface almost as closely as during the warmest months of the
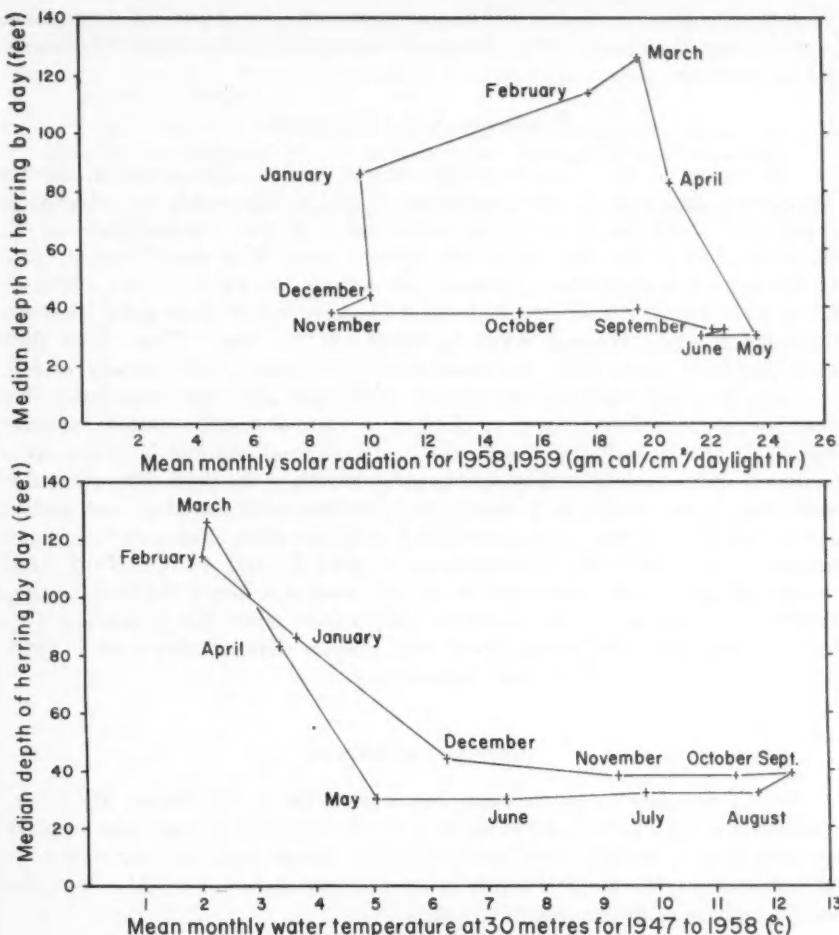
FIG. 5. *Above:* Mean monthly solar radiation and depth of herring by day (unweighted data).
         Below: Mean monthly water temperature and depth of herring by day (unweighted data).

year. This would suggest that no simple temperature effect on activity was responsible for the correlation between 2° and 4–7°C.

It was shown above (p. 703) that herring show a cycle of vertical depth changes from a position deeper in the water by day to a position near the surface at night in all the months of the year. Although on a seasonal basis the depth by day is not correlated with solar radiation it is still possible that changes in light intensity are responsible for the direction of movement but not its extent.

When temperatures are below 7°C the correlation between depth and temperature suggests that the extent of the downward movement by day might be governed by temperature.

SUMMARY AND DISCUSSION

In terms of the Passamaquoddy power project, this study of herring distribution shows that a large proportion of the herring population coincides in depth with the filling gates in the dams and with the intake channel to the turbines. During the months of the fishery, from May until October, 75% of the herring recorded were between the surface and 44 ft (13 m) while the filling gates would extend from 10 to 40 ft (3–12 m) below mean water level and the turbine intake channel would be 45 ft (14 m) deep. Thus, from their vertical extent alone, these structures should not obstruct the passage of fish.

The results of more general interest which arise from this investigation are linked with the ability to observe changes in vertical distribution of immature herring in one locality throughout the year. Diurnal changes in depth are a feature of the behaviour of these fish in every month of the year. On a monthly basis there is no correlation between mean daytime solar radiation and median depth of herring by day; but a correlation exists between median herring depth and mean monthly water temperatures between 2° and 4–7°C. Thus while changes in light intensity may initiate diurnal changes in depth, the final daytime depth of the fish may be governed by temperature when this is below 4–7°C, cooler temperatures being associated with greater depths. Above 4–7° there is no change in herring depth with temperature.

ACKNOWLEDGMENTS

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Effects of Proposed Passamaquoddy Power Project on Anadromous Fishes in Canadian Waters[1,2]

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ABSTRACT

Atlantic salmon, smelt, alewives, shad, eastern brook trout, and introduced brown trout occur in waters that will be affected by the Passamaquoddy power project. The first four species are taken occasionally in herring weirs but total annual landed values did not exceed $6,000 in the period 1937 to 1956. Salmon and trout have high potential value for angling, subject to improvements in local river management.

Construction of tidal power dams should overcome the present lack of typical estuarine conditions in the Passamaquoddy area and favour production of anadromous species. An improved sport fishery for sea-run trout could develop. Realization of the potential production of Atlantic salmon, alewives and shad, but possibly not sea-run trout, would depend on satisfactory access from the Bay of Fundy to the impounded areas.

INTRODUCTION

THE ANADROMOUS FISHES that have present or potential economic value in the vicinity of Passamaquoddy Bay include the Atlantic salmon, smelt, alewife, shad, eastern brook trout, and some introduced trout species. Elsewhere in eastern Canada the first four provide valuable commercial fisheries, but in the Passamaquoddy region they are taken only occasionally, mostly in herring weirs. In nearby rivers, angling catches of salmon and trout are now small by comparison with catches elsewhere around the Atlantic coast. For these reasons none of the anadromous species were included in the special biological investigations that were undertaken in connection with the proposed Passamaquoddy tidal power project (Hart and McKernan, 1960). Only meagre information has been available on which to base a forecast of effects of the dams on the various species, as requested by the International Passamaquoddy Fisheries Board.

Anxiety has been expressed particularly about the effects of the power project on the salmon sport fishery in rivers that flow into Cobscook and Passamaquoddy Bays (Fig. 1). Only minor economic importance can be assigned to it at present, but there is steadily growing appreciation of the recreational value of all sport fisheries. The Dennys River, flowing into Cobscook Bay in Maine, now has the


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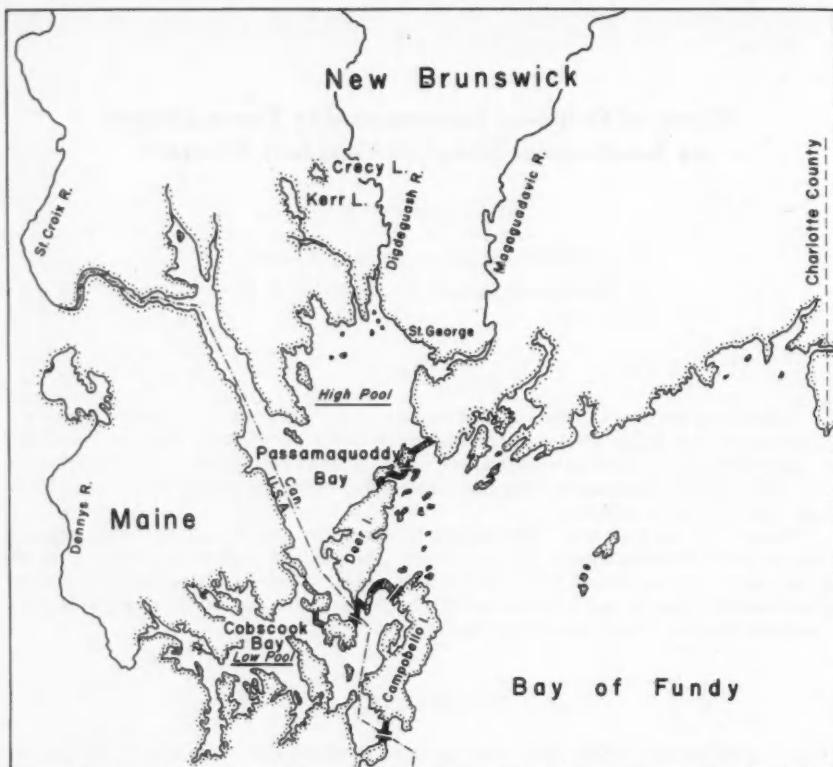
Fig. 1. The Passamaquoddy Region, showing waters in which anadromous fishes occur.

largest angling catch of salmon among the rivers that would be affected. In recent years up to 100 salmon have been caught there in a year, but the annual take averaged 55 in the 1948–1957 period. Even this low yield holds the interest of a group of enthusiastic anglers and supports business estimated by the Maine Department of Sea and Shore Fisheries to be worth about $8,000 annually. In the St. Croix River, salmon are not available now for angling because of impassable dams, but a few are taken occasionally near its mouth. In nearby Canadian rivers like the Digdeguash and Magaguadavic, fair populations of salmon occur but the level of angling success is low. It is believed that salmon angling has a high potential value in these rivers, and might be realized if suitable improvements could be made in the local management of the fishery.

In 1958 it was agreed to recommend that suitable fish passage facilities be provided to prevent the supply of anadromous species from being seriously reduced by the power project. An estimate of the requirements has been made by fishery engineers experienced in providing fishways for salmon at dams on the

Pacific coast (Bell and Clay, 1960).   The facilities would be expected to benefit not only Atlantic salmon and sea-run trout, but also some of the other anadromous species.

HABITS AND UTILIZATION OF VARIOUS SPECIES

Available information on the habits and present utilization of the various anadromous species in Charlotte County waters is summarized below, to provide some background for estimating the effects of the power project on future production.

ATLANTIC SALMON (*Salmo salar*)

Adult Atlantic salmon may enter fresh water from the sea at any time from early spring until the late fall.   In some eastern Canadian rivers an early run predominates; in some, the run is mainly in the fall; others have abundant runs both early and late in the season.   Rivers in the Passamaquoddy area seem to have peak runs during July and August, as indicated by records taken at a trap in a fishway on the Magaguadavic River at St. George, N.B., and by observations of salmon jumping a falls at head of tide on the Digdeguash River. Commonly, adults remain in fresh water overwinter and return to the sea the following spring.   A small proportion, about 10%, of adults may be expected to return for spawning again.   Marking and tagging experiments have shown that homing of adult Atlantic salmon to their rivers of origin is highly developed.

Spawning occurs in October and November, the fertilized eggs develop slowly in the stream bottom through the winter, and hatching of fry occurs in early spring.   Growth of parr occurs in the streams for 2 to 4 years or longer, to produce smolts which migrate to the sea in May and June at a fork length of 5 to 7 inches (13–18 cm).   The habits and possible commercial utilization of salmon produced in streams in the Passamaquoddy area are unknown, since there have been no smolt marking or tagging experiments here.   There is no information on the length of time they stay in Passamaquoddy Bay, nor concerning their destinations in salt water before returning after one year as grilse of 3 to 5 lb (1.4–2.3 kg), or after 2 or more years as salmon of 8 to 12 lb (3.6–5.5 kg), or larger.   Around the coasts of the Maritime Provinces and Newfoundland there is a commercial sea and estuarial fishery by gill nets and trap nets for adult salmon, designed to catch them primarily while they are returning towards their natal rivers for spawning.   In Charlotte County waters, no commercial gear is set specially for salmon but some are taken in the herring weirs.   Studies on other New Brunswick rivers suggest that considerable numbers of salmon produced in local streams are caught in salmon gear set in other sea areas, some of them far distant (Kerswill, 1955).   Angling occurs in fresh water from the spring through the summer, with a preference for early season angling.   Using standard fly-fishing techniques, salmon cannot be caught readily in the dark coloured waters of Charlotte County rivers.   Successful angling might be encouraged by amending fishery regulations to permit other angling methods, such as spin-fishing.

Because adult salmon commonly occur well out to sea, to assure optimum conditions for their development and return to local rivers, fishways would be required to permit ready access from the Bay of Fundy to both lower and upper pools.

SMELT (*Osmerus mordax*)

Adults run from the sea into lower freshwater areas of rivers in the spring, spawn, and return to salt water without delay.   The young smelts run out to sea as larvae within a few weeks.   In many parts of the Canadian Atlantic coast a trap-net or gill-net fishery occurs for adults in salt water of estuaries from late summer to mid-winter.   In some places there is a worthwhile sport fishery using hook and line.   In the Passamaquoddy area except for occasional gill nets no special gear is operated for smelts, but considerable quantities are sometimes taken in herring weirs and marketed.   The fishery statistics for Charlotte County show landings from July to December with peak catches in October and November. There is no information on which to base an estimate of the possible effects of the proposed dams on local smelt production.   From casual observations on smelt behaviour at fishways elsewhere in New Brunswick it is doubted that fishway facilities suitable for other anadromous species would pass smelts.

ALEWIFE (*Pomolobus pseudoharengus*)

Adults enter fresh water from the sea in spring and early summer, to spawn and return, usually within several weeks, to salt water.   The young move out to the estuaries during their first summer.   In many parts of the Atlantic coast a valuable commercial fishery is carried on for alewives as they pass through estuaries on their way to the rivers for spawning.   In some places adults are trapped in fresh water for local consumption.   In the Passamaquoddy area several trap nets for alewives are operated at St. George, N.B., and some are caught in herring weirs.   All Charlotte County landings shown in 1937–1956 statistics occurred in May and June.   Local production of alewives might increase to some extent if the power dams were constructed, because the greater coastal area having typical estuarine conditions might favour their development.

There is considerable knowledge of fishway requirements for alewives and to assure maximum production the fishway facilities of the power project should be made suitable for them.   While most alewives may remain in the vicinity of estuaries it is known that large quantities occur far offshore (Bigelow and Schroeder, 1953).   Thus access should be available from the Bay of Fundy to the tidal pools.

SHAD (*Alosa sapidissima*)

The habits of shad resemble those of alewives.   They are fished along with other anadromous species elsewhere on the Atlantic coast, and provide a valuable fishery in some parts of the Bay of Fundy.   They have never appeared

in fishery statistics for Charlotte County in recent years, but are taken occasionally in herring weirs.   It is possible that altered environmental conditions resulting from the proposed power project might cause increased quantities in the Passama-quoddy area.   Tagging experiments have shown that considerable migrations of shad occur in the sea (Bigelow and Schroeder, 1953).   Fishway facilities to permit access to the impounded areas from the Bay of Fundy would be needed to assure realization of the potential shad production.

TROUT

The eastern brook trout (*Salvelinus fontinalis*) is native to Charlotte County, N.B.   The brown trout (*Salmo trutta*) reared in hatcheries has been introduced. An experiment is now in progress in Crecy and Kerr Lakes (FRB, 1959, p. 71) to learn the possibilities of introducing rainbow trout (*Salmo gairdneri*) to im-prove local trout angling.

Brook trout now provide a sport fishery of considerable value in freshwater streams and lakes of Charlotte County.   Owing to shallow, infertile soil in this hard-rock area, the drainage waters are relatively poor in trout foods.   The fertility of local lakes can be increased, however, by adding commercial fertilizers. Trout production can be increased effectively by combining predator control with fertilization (Smith, 1955).   Some brook trout spend their whole lives in fresh water, others migrate to salt water and are called "sea-run trout" or "sea trout" as they return to the streams.   Spawning of adults occurs in the fall and the young develop in streams similarly to salmon, but prefer somewhat cooler waters. Practically nothing is known about the habits of sea-run trout in the Passama-quoddy area but it is believed that there are few sea-run individuals here.   This is probably related to the lack of suitable estuarine conditions for sea-run trout, associated with the extreme tidal amplitude and the generally low sea water temperatures.   Damming Passamaquoddy Bay would likely improve conditions for sea-run trout, which are so highly prized by anglers elsewhere.

Available information on the habits of sea-run brook trout, though scanty, suggests that they do not move far from their natal streams.   For example, few of the trout produced in Ellerslie Brook, P.E.I., which descend into the estuary, appear to leave it for open coastal waters (Smith and Saunders, 1958).   Similarly most of the sea-run trout produced by streams flowing into the upper and lower pools of the proposed power project might stay within this new estuarial area. It is possible, therefore, that free access from the Bay of Fundy through fish-ways is less important for sea-run brook trout than for salmon, shad and alewives.

Introduced brown trout seem to be thriving in local rivers and are contributing effectively to angling catches.   Again, little is known about their sea-running habits but the proposed dams might lead to more of the sea-run type.   The same would probably apply to rainbow trout if they were introduced to streams inside the dams.

PRESENT VALUE OF FISHERIES FOR ANADROMOUS SPECIES

COMMERCIAL FISHERY

Annual total landings and landed values of Atlantic salmon, smelt and alewives in the four statistical districts of Charlotte County, N.B., during the 20-year period of 1937–1956 are summarized in Table I as averages by 5-year periods. The quantities are low, as might be expected, since most of the catches are made incidentally by the herring-weir fishery.

TABLE I. Anadromous fish taken by commercial gear, Charlotte County, N.B., 1937–56. (1 lb = 0.45 kg).

	1937–41	1942–46	1947–51	1952–56	20-year average
Average annual landings, in pounds					
Salmon	40	...	...	...	10
Smelt	7,260	3,560	5,120	60	4,000
Alewife	...	580	120,340	84,080	51,250
Average annual landed value, in dollars					
Salmon	8	...	...	...	2
Smelt	489	758	613	12	468
Alewife	...	6	967	581	388

The single recorded salmon landing of 200 lb in 1938, practically all the alewife landings and over half the smelt catch, were made in the one Statistical District, No. 52, which comprises Passamaquoddy Bay, the high pool area. In all four Charlotte County districts, No. 50 to 53 inclusive, smelts were shown for only 13 of the 20 years with a maximum annual value of $1,611 for 9,200 pounds landed in 1949. Alewives were listed for only 8 of the 20 years, and the maximum annual value of $4,122 occurred in 1949 when 484,900 pounds were landed.

SPORT FISHERY

Although some Atlantic salmon and many trout are caught by angling in Charlotte County waters reliable figures for the annual catch are lacking. No effort has been made to, obtain an accurate creel census of sea-running fish caught in the streams here. An attempt has been made, however, to guess the number of salmon and sea-run trout that are now available to anglers and the value of the fraction that may be caught. The rough estimate of availablity of adults is based on limited knowledge of the populations of young fish in the local streams combined with information from other New Brunswick streams on rate of survival from young to adults.

Under present conditions, with impassable obstructions and pollution on the St. Croix River and imperfect fishway facilities at the falls on the Magaguadavic River, perhaps 1,500 salmon now enter tributaries to Passamaquoddy Bay in an average year. Of these, 20% might be caught by anglers giving an estimated annual catch of 300 salmon. Recently economists have attempted to estimate

the economic benefits of the salmon fisheries in the provinces of New Brunswick and Quebec (Grasberg, 1956; Maheux, 1956).   In New Brunswick where anglers catch about 45,000 annually the value per angled fish seems to be about $25, in Quebec about 12,000 are angled annually worth about $160 each.   Using the more conservative New Brunswick average figure, the estimated value of the present salmon angling catch in the Passamaquoddy area would be $7,500.

It is guessed that 2,000 sea-run trout, including brook trout and brown trout, may now return to Passamaquoddy rivers each year.   If 20% of these or 400 are caught annually and a value of $3 per fish is assigned as a fair fraction of the above estimated value for New Brunswick salmon on a weight basis, the present value of the sea-run trout fishery would be $1,200.

POTENTIAL VALUE OF FISHERIES FOR ANADROMOUS SPECIES

It should be possible now, in the absence of power dams, to start improving the inland conditions of local rivers and so bring about greatly increased production of anadromous fishes in the Passamaquoddy area.   Some idea of the productive capacity of only the St. Croix River drainage is given in the report of the International St. Croix River Engineering Board to the International Joint Commission, 1957.   It was estimated that installation of fishways at existing dams and other stream improvements could allow production of enough salmon smolts to give an annual return of 9,000 to 18,000 adult salmon.   These salmon could provide angling worth from $45,000 to $90,000 per year, assuming as before that 20% could be caught and that $25 is a reasonable value for each angled fish. The freshwater producing areas that would become available in the St. Croix drainage area might produce also enough young fish for an annual harvest worth $50,000 for alewives and $7,000 for shad.

As suggested above, installation of the power dams should not be detrimental to most of the anadromous fishes produced in the rivers flowing into the impounded areas, if suitable fish passage facilities are incorporated in the structures. Production of some species might even be increased beyond previous levels because an extensive coastal area with estuarine conditions would be created.

One of the useful developments that could result from the power project is an improved sport fishery for sea-run trout.   Some idea of the number of adult sea-run brook trout that might be produced by streams flowing into Passamaquoddy Bay if the dams were installed, can be derived from information on the production of these fish under comparable conditions elsewhere.   Malpeque Bay, P.E.I., has about the same area as Passamaquoddy Bay and is the estuary of about 20 trout streams, including Ellerslie Brook where brook trout production has been studied extensively (Smith and Saunders, 1958).   The average annual production of sea-run brook trout by Ellerslie Brook is estimated to be around 2,000.   It is reasonable to assume that all the streams tributary to Malpeque Bay produce about 40,000 sea-run brook trout annually.   Passamaquoddy Bay might give a similar production if it had new estuarial conditions that would

be somewhat similar to those of Malpeque Bay. Although streams in the Passamaquoddy area are less fertile than Prince Edward Island streams, this deficiency might be overcome by the size of several Passamaquoddy streams, which are many times longer than any tributaries to Malpeque Bay.

There are no facts on which to base an estimate of the extent to which sea-run brook trout production might be augmented by the other trout species like the introduced brown trout. A figure of 10,000 is assigned, however, bringing the total annual adult sea-run trout stock to 50,000 fish. If anglers caught 20% of the available fish and if they were worth $3 each, the value of the sea-run trout fishery would be $30,000 annually or about 25 times the present estimated value.

Obviously it is impossible to forecast how the returning adults of the anadromous species would distribute themselves in the tidal pools with respect to the International Boundary, if the power project becomes a reality. The potential value of the fisheries cannot be estimated for Canadian waters alone.

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NOTES

Temperature Tolerance of Unacclimated Herring
(*Clupea harengus* L.) [1]

Herring have been caught in surface gill nets in water of temperatures up to 18°C in the summer and have been seined in the winter after being present for at least 5 days in water that was close to 0°C from top to bottom (Leim *et al.*, 1957). Thus herring occur naturally in a wide temperature range. Battle *et al.* (1936) have shown that captive herring subjected to natural seasonal variation in temperature continued to feed in water of 0.75°C. In the present investigation herring were seen through a crack in the ice to be swimming actively 6 to 9 inches above the bottom in water of −0.3°C, in a large pen which communicated with the sea at high tide. Herring, therefore, appear to behave normally at the lower end of their reported temperature range.

Several determinations of the upper lethal temperature of herring were made and are described here together with notes on the survival of herring after brief exposure to low, naturally produced temperatures. Most of the recent lethal temperature determinations have been based on results obtained with fish previously acclimated by prolonged exposure to constant temperatures. Only in this way can consistent results be obtained. These experiments have shown that the temperature tolerance of some fish increases with an increase in the acclimation temperature (Fry *et al.*, 1942). In the present investigation an attempt was made to acclimate herring at 5, 10 and 15°C. After 4 weeks, mortalities ranged from 14 to 30% leaving a selected stock which was unsuitable for further work. Consequently, the determinations of the upper lethal temperature were made on unacclimated fish most of which were captured immediately prior to being tested. Using recently caught herring had the additional advantage that the fish were tested in their natural condition of fatness and had fed only on natural food. This latter point is of importance as it has been shown that the temperature tolerance of some fish can be altered by changes in the nature of the oils fed to them in captivity (Hoar and Dorchester, 1949).

In the present investigation the upper lethal temperature was defined as the temperature that would cause 50% mortality in 48 hours.

MATERIAL AND METHODS. Herring were obtained from weirs in Passamaquoddy Bay, N.B., or its approaches, during normal seining operations. At each transfer from one carrying container to another, the fish were surrounded by a dip net and a few caught with water in a plastic bucket which was immersed in the

[1]International Passamaquoddy Fisheries Board, 1956–59. Scientific Report No. 20.

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next container to release them. By this means the herring were taken from the weir to the experimental tanks without removing them from water.

The determination of the upper lethal temperature in June 1958 was made on fish held for 8 days at 8.7 to 11.2°C, which was similar to temperatures naturally occurring at that season. All other determinations were made on the day that the herring were taken from the weir. In all experiments the size composition of groups of herring tested at different temperatures was made as similiar as possible. The water in all test tanks was continuously renewed and aerated.

RESULTS. The details and results of each experiment are summarized in Table I. The temperature of water in the weir was not taken in June 1959, but

TABLE I. Details and results of determinations of the temperature which would cause 50% mortality in herring after 48 hours exposure (upper lethal temperature). The last two rows represent different size groups in one batch of fish caught and tested together.

| Date | Length test fish | | Weir or stock tank temperature | Average No. of test fish | Mortality in control | Upper lethal temperature |
	Range	Mean				
	cm	cm	°C	no.	%	°C
June 1958	10–18	13.6	8.7–11.2	25	7	19.6
June 1959	10–22	15.3	8.1	20	0	<19.0
July 1959	12–22	17.6	9.9	30	0	19.6
October 1958a	9–12	11.1	9.6	20	0	21.2
October 1958b	17–30	21.9	9.6	9	0	19.5

may be assumed to be close to the surface temperature at the Biological Station at that time which was 8.1°C. Thus all results apply to fish from water at 8 to 11°C and these fish commonly were found to show a temperature of about 19.5°C as the point at which 50% of the group would die after 48 hours exposure. Assuming that the herring are undergoing a seasonal shift in their acclimation to temperature two pairs of results are of interest. For the two June determinations, the herring with the greater mean length show the lower upper lethal temperature. In October 1958 one determination was made but the fish stock tested consisted of two quite distinct size groups, shown separately in Table I. When the mortalities at 23 and 21°C were considered it was found that there was a significant difference between the mean length of the first ten and the second ten that died in 'each tank. There was thus in this determination a differential mortality with size; the larger herring dying more quickly at high temperatures than the smaller ones. There is not sufficient evidence to determine whether herring show seasonal changes in their resistance to high temperatures.

SURVIVAL OF HERRING AFTER BRIEF EXPOSURE TO LOW TEMPERATURES. No experimental determination of the lower lethal temperature of herring was made. However, an accidental occurrence suggests that herring can survive at least brief exposure to low temperatures. In December 1958 an outside stock tank was found to have a thin covering of ice. The surface temperature immediately below the ice was −1.1°C and the bottom −1.4°C. Out of at least 210 herring in this tank only 27 were dead, so 87% or more were not killed

immediately by these temperatures. The surviving herring were transferred to water of 7°C and at least 63% of the original number were still alive after one week. As the handling mortality is unknown, 63% is a minimum value for the survival of herring for one week after cooling to below −1.0°C.

DISCUSSION. The results obtained in this preliminary study suggest that herring in nature occupy almost all the temperature range which is permitted by their resistance to temperature extremes. Herring of the Canadian Atlantic coast have been caught in water from 0 to 18°C (Leim *et al.*, 1957). Herring at the appropriate season have an upper lethal temperature of 19.5 to 21.2°C, according to size, and can survive short exposure to temperatures below −1°C.

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Survival of Herring (*Clupea harengus* L.)
in Water of Low Salinity[1]

Bigelow and Schroeder (1953) give 28‰ as approximately the lower salinity tolerance of herring. However, the occurrence of herring in estuaries suggests that these fish enter and live for at least short periods in water of lower salinity. McKenzie (1959) recorded the taking of juvenile herring from the Miramichi estuary from water of 20 to 22‰ salinity. Water with a salinity of 17‰ was used by Parrish, Blaxter and Holliday (1958) to reduce the initial mortality of herring after capture. Fertilization and hatching of herring eggs are possible in water of 4.8‰ (Ford, 1929) and a salinity of 1.7‰ has been found on herring spawning grounds (Bückmann *et al.*, 1953).

The ability of herring of the Passamaquoddy region to survive at various low salinities was investigated in this experiment.

Herring ranging in size from 10.2 to 24.2 cm were used in the experiment. They had been held overwinter in tanks supplied with sea water whose salinity usually varies between 28 and 32‰. Twenty fish were tested at each salinity, except the sea-water control which had nineteen herring. Each group was held in 332 litres of water in a circular fibreglass tank. Fresh water for the dilution of sea water to 10‰ and 25‰ came from melted snow; filtered pond water was used for other dilutions and the fresh water tank. The water was aerated but not renewed and its temperature kept between 4°C and 8°C except on two days when the temperatures in the 20‰ and fresh water tanks rose to 14°C. All these temperatures are within the temperature tolerance limits of herring. The fish were fed occasionally on chopped *Gammarus*. A hydrometer was used to determine the salinity. Salinities during the experiment were within 0.6‰ of the average value given in Table I.

The number of fish dying in each week of the 4-week test period is shown in Table I.

In fresh water the herring swam continuously. After several hours scales along the flanks of the fish stood out from the body. After the first 4½ hours in fresh water half of the group died and all were dead before the end of the first 24 hours.

In water of 5‰ or greater salinity the herring appeared to be able to osmoregulate so that deaths over the test period were few and irregularly distributed with respect to salinity. This irregular distribution suggests that mortality might be due to incidental factors, such as the failure of a few fish to feed under experimental conditions. Even at 5‰ most of the small herring would take food, though not quite so readily as fish at higher salinities.

The experiment showed that herring 10 to 24 cm long are very resistant to lowered salinity, being able to withstand salinities down to 5‰ for 4 weeks

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TABLE I. The mortality of herring 10 to 24 cm long, at different salinities over a four-week period.

Number of fish	Average temperature	Average salinity	Deaths in each week				Percentage dead at 4 weeks
			1st	2nd	3rd	4th	
	°C	‰	no.	no.	no.	no.	%
19	6.1	31.9	0	0	0	0	0
20	5.7	25.6	0	0	0	0	0
20	6.8	20.1	1	1	1	1	20
20	5.5	10.2	0	0	0	1	5
20	5.9	5.2	0	1	1	1	15
20	9.1	<0.1	20	–	–	–	100

with only low mortalities when tested at temperatures mainly between 4 and 8°C. These temperatures are similar to those found in the Passamaquoddy region at the time of the spring thaw when critically low salinities are most likely to be encountered by herring in estuaries, enclosed bays, or in the waters impounded by the proposed Passamaquoddy power project.   The experimental results suggest that short exposure of herring to these low salinities is unlikely to have any direct adverse effect on the fish unless the salinity falls below 5‰.

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Current Measurements in Passamaquoddy Bay and the Bay of Fundy 1957 and 1958[1]

Currents were measured at sixty stations in Passamaquoddy Bay and the Bay of Fundy during the summer of 1957 and 1958 (Fig. 1). This project was carried out jointly by the Canadian Hydrographic Service of the Department of Mines and Technical Surveys, and the Atlantic Oceanographic Group of the Fisheries Research Board of Canada, and an interim report was prepared (Forrester, 1958). The program, aimed at determining the tidal and non-tidal water movements in Passamaquoddy Bay, in its approaches, and in part of the Bay of Fundy, constituted an important element in the oceanographic studies carried out for the International Passamaquoddy Fisheries Board (Hart and McKernan, 1960).

Field surveys were conducted during the summer months of 1957 and 1958 using two vessels, the 84-foot *Harengus* belonging to the Fisheries Research Board, and the 49-foot *Mercury*, a chartered fishing boat. During the early part of the 1957 season, observations were made from a drilling barge employed by the United States Corps of Engineers to take bottom core samples in the entrances to Passamaquoddy Bay. Most of the data were gathered with current meters suspended from an anchored ship and read at half-hour intervals. At each station, water samples and temperatures were taken at various depths using reversing water bottles and bathythermographs.

None of the current-measuring equipment was ideal for the conditions encountered. The Ekman current meter was used most extensively and was supplemented by the Chesapeake Bay Institute drag and the Gurley current meter. The Ekman propeller releasing and locking device did not function properly at the high velocities encountered. The Gurley meter registered unreliable velocities in rough seas, and the drag assumed exaggerated wire angles at high velocities. Only by using the three methods and balancing the flaws of one against the advantages of another were reasonably reliable results obtained.

Tides in the Bay of Fundy are characterized by a predominant semidiurnal component. For this reason, some stations were observed over only a 13-hour period, ignoring longer-period components, to enable more stations to be occupied. However, most of the stations were observed over a 25-hour period. Three key stations were occupied for 72 hours to strengthen the accuracy of the results.

In the mentioned interim report tidal stream and residual current information obtained at each anchor station was presented in both tabular form and in the form of synoptic charts showing the tidal stream at hourly intervals with reference to time of high water at Saint John, N.B. Tidal stream velocities and directions were shown for three depths at each station. Velocities were adjusted proportionately to a range of tide of 21 feet at Saint John. Velocity and direction of the residual current at each of the three depths were shown. The report was essentially an analysis of data and no conclusions were drawn.
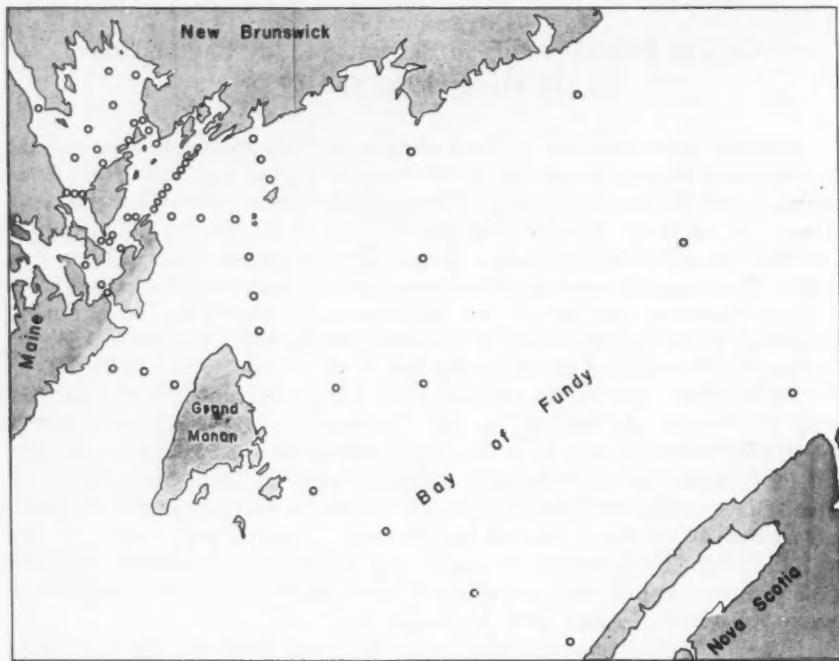
FIG. 1.   Current-measuring stations in Passamaquoddy Bay (upper left corner) and in the Bay of Fundy.

Results indicate that the tidal currents vary markedly throughout the region.   Maximum recorded speeds were found in Letite Passage where mean maximum speeds reached 8 feet per second (4.8 knots).   In Passamaquoddy Bay, speeds were mostly less than 1 foot per second.   Near the mouth of Cobscook Bay mean maximum speeds were 5 feet per second.   In the outside area, mean maximum speeds seldom exceeded 5 feet per second.   Currents were usually maximum in the surface layer and decreased slowly with depth.   Residual flows were mostly less than 2 miles (nautical) per day in Passamaquoddy Bay, Cobscook Bay and the approaches.   In the Bay of Fundy, residual flows were variable and in some areas were as much as 10 miles per day.

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Records of Uncommon Fishes from Waters off the Maritime Provinces of Canada

The following records of unusual fish from the waters off the coasts of New Brunswick, Nova Scotia, and Prince Edward Island, have accumulated since a more extensive list was published (Leim and Day, 1959). All of the specimens mentioned below, except the hagfish and capelin, have been seen by the writer. Members of the staff of the Fisheries Research Board of Canada Biological Station, St. Andrews, who have provided fish and data, are shown in parentheses.

Myxine glutinosa Linnaeus   HAGFISH

On July 19, 1959, Dr A. G. Huntsman noticed a small hagfish swimming at the surface of the water near Deer Island Point, N.B., while conducting a group of students. The fish was captured and was 11½ cm (4½ in) long. This appears to be another instance of a deep-living form being carried to the surface by the turbulence in the area.

Centroscyllium fabricii (Reinhardt)   BLACK DOGFISH

Taken frequently in trawls by the Board's research vessel *A. T. Cameron* in the neighbourhood of Emerald Bank in August, 1959. The smallest specimens were 15 to 20 cm (6 to 8 in) long. (Mr A. C. Kohler.)

Mallotus villosus (Müller)   CAPELIN

Spawning capelin were reported as abundant on the beaches at Gabarus and Fourchu, N.S., in June, 1958 and 1959. Fishermen stated that they had not seen capelin there for many years. (Messrs R. J. Gibson and D. E. Graham.)

Capelin were found frequently in cod stomachs in the Miscou-Chaleur Bay area during the summer of 1959. (Dr Y. Jean.)

Alepisaurus ferox Lowe   LANCETFISH

A specimen, 128 cm (50 in) long, was forwarded by Dr W. J. Dyer, Fisheries Research Board of Canada Technological Station, Halifax, N.S. It was caught in 150 fathoms by the long-liner *Muriel Isabel*, while fishing in the "Gulley" between Banquereau and Sable Island Bank, in early November, 1959. A second specimen was not landed.

Urophycis tenuis (Mitchill)   WHITE HAKE

A specimen, 126 cm (49½ in) long and weighing 43½ pounds, was caught between Eastport, Maine, and Deer Island, N.B., on July 28, 1959, by Mr Chas. S. Livingstone, Red Beach, Maine. Slightly larger specimens have been reported

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from the region (Scattergood, 1953) but such large hake are uncommon.   This specimen is preserved in the National Museum of Canada at Ottawa.

Syngnathus fuscus Storer   COMMON PIPEFISH

A specimen, 21 cm (8¼ in) long, was washed ashore at Hawk Point, near Cape Sable, N.S., in late July, 1959.   It was forwarded by Fisheries Officer W. A. Quinlan, Clark's Harbour, N.S.   This appears to be the first record from southwestern Nova Scotia, although the species is doubtless common in the sandy areas there.

Sarda sarda (Bloch)   COMMON BONITO

A specimen, 28 cm (11 in) long, was found among mackerel catches of Lunenburg fishermen in August, 1959.   (Mr M. F. Fraser.)

Poronotus triacanthus (Peck)   BUTTERFISH

Gulf of St. Lawrence records of this species are so infrequent that the capture of a specimen, 12 cm (4¾ in) long, by the dragger *Gloucester No. 15* in November, 1959, is noted.   The boat was fishing in 50 fathoms, northeast of Shippegan Gulley, N.B.   The specimen was sent in by Fisheries Officer L. N. Arsenault, Lameque, N.B.

Seriola zonata (Mitchill)   BANDED RUDDERFISH

A specimen, 18 cm (7 in) long, was caught on Lahave Bank in August, 1959, by Captain J. Atkinson.   (Mr M. F. Fraser.)

Stenotomus versicolor (Mitchill)   SCUP

Captain J. Fitzgerald caught a 26-cm (10¼-in) specimen, while dragging off Pendleton Island, Passamaquoddy Bay, N.B., on October 15, 1959.   (Dr W. R. Martin.)

Lopholatilus chamaeleonticeps Goode and Bean   TILEFISH

A specimen, 90 cm (35½ in) long, was caught on Emerald Bank, in March, 1959.   (Mr M. F. Fraser.)

Cyclopterus lumpus Linnaeus   LUMPFISH

A specimen, 46 cm (18 in) long, was caught 2 miles off Northport, N.S., in May, 1959.   It was forwarded by Fisheries Officer R. P. Ripley, Oxford Junction, N.S.   This is the first record for the Northumberland Strait area.

Balistes carolinensis Gmelin.   TRIGGERFISH

A specimen, 49 cm (19¼ in) long, was caught at the entrance to Lunenburg Harbour, N.S., in August, 1959, by Mr Perlie Levy.   The caudal lobes were greatly prolonged; identification was confirmed by Mr W. C. Schroeder, Museum of Comparative Zoology, Cambridge, Mass.   (Mr M. F. Fraser.)

Sphaeroides maculatus (Bloch and Schneider)   PUFFER

A specimen, 21 cm (8¼ in) long, was caught in a weir at Northwest Harbour, Deer Island, N.B., in late October, 1959.   It was forwarded by the owner, Mr Osgood Leslie, Leonardville, N.B., through Fisheries Officer W. C. Hodges, St. Andrews, N.B.

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Explorations for Herring in the
Bay of Fundy and Gulf of Maine[1]

The Passamaquoddy investigations (Hart and McKernan, 1960) included an exploratory-fishing project designed to supplement the shore-sampling program and to locate schools or populations of herring that were not being subjected to commercial exploitation. Most of the work was done in the Passamaquoddy area of New Brunswick but there were cruises to Georges Bank and in the Kennebecasis and Long Reach areas of the Saint John River.

The program included fishing experiments with bottom and pelagic trawls, with baited long-lines ("line trawls"), and with gill nets. Sonic-sounder surveys were made weekly in Passamaquoddy Bay during the summer and early autumn of 1958 and frequently but irregularly in other areas and seasons.

The amounts of herring taken with experimental gear in the Passamaquoddy area were small. There was echo-sounder evidence however of extensive distribution, with most of the large schools appearing in open areas away from the small coves and inlets where most herring weirs are located. This was confirmed on one occasion by commercial purse-seine operations in the open waters of Passamaquoddy Bay where during the first 2 weeks of September 1958, 5 seiners caught more than $2\frac{1}{4}$ million lb (1020 metric tons) of herring.

A large spawning population of herring was discovered on the northern edge of Georges Bank. Mature fish, some of them in the ripe and running stage, were taken with bottom trawls in quantities of 2,000 to 5,000 lb (910–2300 kg) per tow at depths of 60 to 90 fathoms (110–165 m). The largest catch for a single tow was estimated at 17,000 lb.

Investigations were carried out in the Kennebecasis and Long Reach areas because some of the physical characteristics of that region seemed to be similar to those expected in Passamaquoddy Bay if dams were installed. Catches showed that the species of fish found there were the same as those common to the Quoddy Region (Trites, 1960).

For Passamaquoddy study purposes, perhaps the most useful result of these explorations is embodied in the echo-sounder surveys. Estimates of the minimum density of herring making up echo traces may be made when part of a herring school is seined and the catch known. For example, (Fig. 1, top left) a boat fishing in Seal Cove, Grand Manan, Dec. 14, 1959, recorded a herring school 30 ft (9 m) in thickness within seining depth and in one set caught 125 to 150 hogsheads (153,000–184,000 lb, 69,000–83,000 kg). Assuming that the seine had a diameter of 200 ft (61 m) these captured herring were occupying 942,600 cu ft (26700 m^3) giving a density of 1 lb of herring to every 5 or 6 cu ft of water (3 kg/m^3). This is regarded as a minimum density as it takes no account of fish escaping before the seine was closed.
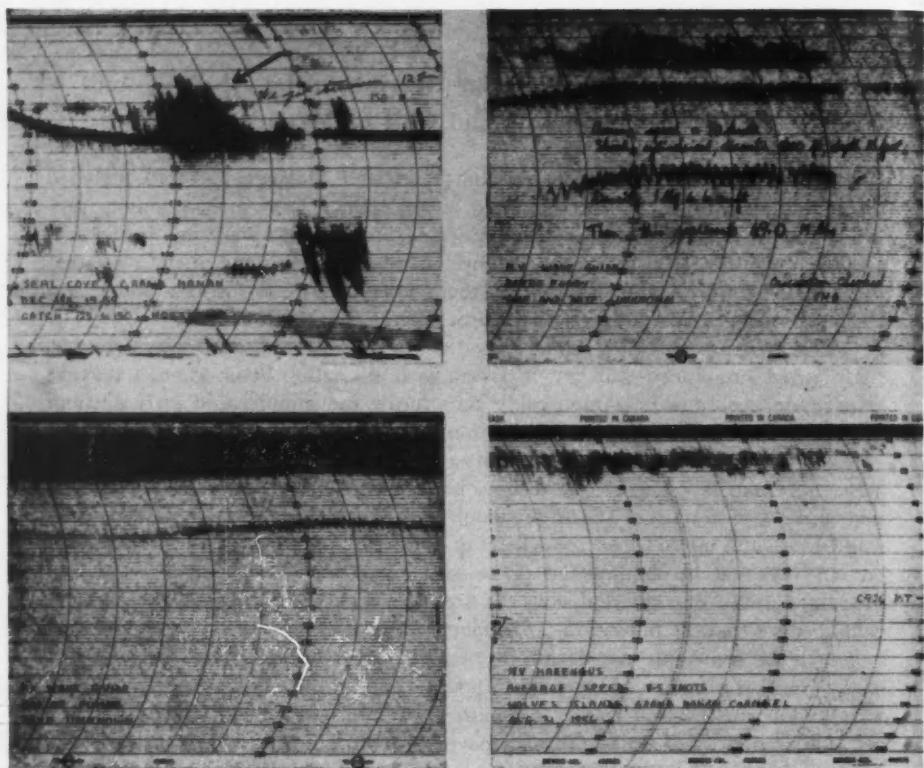
FIG. 1. Echo sounder records of large schools of herring in the Bay of Fundy region.
Top left—Seal Cove, Grand Manan, Dec. 14, 1959.
Top right—Bay of Fundy, date unknown.
Bottom left—Same cruise as top right.
Bottom right—The Wolves, Aug. 31, 1956.

Using this density factor it is possible to make an estimate of the quantity of herring recorded on the echo sounder provided the fish traces are similar to those recorded when the fish were seined. In estimating herring quantities, the assumption is made that the schools are circular in area, that the boat traverses the diameter of the school, and that the average thickness recorded is true for the whole school. In one cruise made by M.B. *Wave Guide* in the Bay of Fundy the boat passed over one school of herring which, assuming a speed of 10 knots (19 km/hr) and fish density of 1 lb in 6 cu ft (2.7 kg/m³), represents 49 million lb (22,000 metric tons) of fish (Fig. 1, top right). On this same cruise 40 similar schools of herring were recorded, some of them coalescing to form an almost continuous trace (Fig. 1, bottom left). Another record, part of which is shown in

Fig. 1, bottom right, made by M.V. *Harengus* on August 31, 1956, covered a 37-mile cruise from St. Andrews through Letite Passage to Beaver Harbour and thence by The Wolves to Grand Manan. Ignoring fish traces which at the average speed of 8.5 knots were less than 50 ft across, it was calculated that the quantity of herring passing beneath the vessel during this cruise was 54 million lb (25,000 metric tons). Obviously, this represents but a small fraction of the herring population in the area at the time. These examples suggest that the average annual catch of 78 million lb (35,000 metric tons) for the Bay of Fundy (McKenzie and Tibbo, 1960) is small compared with the total herring population.

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A Note on Two Stocks of Steelhead Trout (*Salmo gairdneri*) in Capilano River, British Columbia

So-called "seasonal races" of anadromous fishes have been recognized for many years (Rich and Holmes, 1929; Berg, 1934). These races or runs, well known in Pacific salmon (*Oncorhynchus* spp.), may be separated by differences in time of entry to spawning streams, by differences in sexual development on leaving the ocean, by length of residence in fresh water before spawning, or by various combinations of these or other characters. Vernon (1957) showed that significant morphological differences occurred in stocks of kokanee or non-anadromous sockeye salmon (*O. nerka*) in three areas in one large lake. At the same time, field observations suggested that timing of runs in the three areas was not completely concurrent. Neave (1949) recognized three stocks of rainbow trout (*Salmo gairdneri*) in the Cowichan River system; one of these stocks was resident in the Cowichan River, while the other two were of the anadromous (steelhead) variety, and showed seasonal differences as to time of entry to the river and also as to time of spawning.

The steelhead trout is distributed widely on the Pacific coast of North America, from the California–Mexico border to Bristol Bay in Alaska (Carl *et al.*, 1959). Steelheads are known to enter some rivers in each month of the year, but in most streams their arrival from the ocean is fairly well confined to a 2- or 3-month period, and probably is influenced to a large extent by stream flows.

Typically, steelheads enter fresh water from the ocean with little external evidence of the secondary sexual characteristics usually associated with spawning rainbow trout. In males, development of teeth, hooking of the snout and red colour on the gill covers and along the lateral line may be totally absent, while females may retain the silvery appearance of ocean fish until spawning is well advanced.

Two seasonal stocks of steelheads are described in this paper: (1) "winter" fish, which enter fresh water from the ocean usually from December through March in a condition close to sexual maturity, and (2) "summer" fish, which usually enter between early May and early August, in a sexually immature state. Winter steelheads spawn in March or April, generally after they have been present in fresh water for no longer than 3 or 4 months, sometimes much less. Summer steelheads, on the other hand, while spawning at much the same time as winter fish, usually have been present in fresh water from 9 months to a year before spawning, and have spent a complete summer and winter in the spawning stream.

In many British Columbia streams a noticeable "peak" occurs in upstream

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migration.   On the Thompson, Vedder (Chilliwack), Chehalis and Bella Coola
Rivers, winter fish are present in largest numbers in December through February.
On Qualicum, Little Qualicum, Cheakamus, and Nahatlatch Rivers, winter fish
arrive from February through April, with the runs on the latter two streams
confined mainly to April and early May.   On other rivers, such as the Coquihalla
and Silver (near Hope), migration may be confined largely to summer fish, which
enter these two streams mainly in May and June.   On the Dean River and Brem
River migration of summer steelheads is confined largely to July and August.

In at least two streams (Capilano River and Seymour River, North
Vancouver) both winter and summer steelheads may ascend from the ocean during
the same period (April, May) although summer fish may continue to enter these
rivers as late as mid-August in some years.   So-called winter fish on the Capilano
River are heavy with sexual products and can easily be spawned artificially at
the time of their capture.   On the other hand, summer fish migrating upstream
at the same time as winter fish on the Capilano show almost complete lack of
sexual development, and must be held until the following March or April before
they can be spawned.

Steelheads have been trapped on Capilano River, about 3 miles upstream
from salt water, since 1955, when the Cleveland Dam, operated by the Greater
Vancouver Water District, was completed.   In 1956 and in 1957 summer fish
were removed from the trapping facilities and eventually were successfully
spawned at Cultus Lake hatchery, near Chilliwack, B.C., in each case.   Both the
1956 and 1957 summer steelheads were retained for a year and were spawned
in 1957 and 1958 respectively.   At the same place and time, mature winter fish
were trapped during their spawning migration in 1957 and 1958, and were spawned
shortly after capture.   Progeny from these groups were reared separately and
released in Capilano River as follows: yearling smolts in 1958, from the 1957
spawning; and 2-year-old smolts in 1960, from the 1958 spawning.

In 1959 a final group of 30 summer steelheads was transferred from Capilano
River to Cultus Lake hatchery and retained over the winter of 1959–60.   A
group of 34 winter steelheads was transferred from Capilano River to Cultus
Lake hatchery on April 8, 1960.   On April 13, 1960 these winter steelheads,
together with the summer steelheads from 1959, were spawned.   Nine females
and 8 males were utilized from the winter group, and 9 females and 3 males from
the overwintered summer group (of which all of the males but 3 had died during
the winter).   Nine samples of fertilized eggs from each group are now being reared
in adjacent troughs in Cultus Lake hatchery.

Summer steelheads retained at Cultus Lake hatchery for eleven months,
in each of the three years, were not fed.   It is not known whether they normally
feed in streams during the freshwater period of maturation, but high survival
at the hatchery suggests that food in fresh water is not essential to survival and
successful maturation in nature.

Obvious differences exist between adult spawning "winter" and "summer" steelheads from Capilano River.   At the time of spawn-taking, summer fish which had overwintered exhibited the typical bright red "rainbow" colouration on the gill covers and along the lateral line.   Males had well-developed hooked snouts, and both in females and in males, the tips of the gill rakers were flattened and bifurcated.   Winter fish, on the other hand, showed almost no evidence of the secondary sexual characteristics commonly recognized in spawning rainbow trout.   Little red colour was present, even in males, and there was no flattening or bifurcation of the extremities of the gill rakers.   A significant difference occurs, of course, in physiological development, since summer fish enter fresh water in an immature state, while winter fish spawn shortly after leaving the ocean.

Such obvious differences in two groups of fish of the same species, migrating into the same river, in part during the same time of year, bear careful investigation. Whether the various observable differences are genetic or environmental or a combination of both will not be known until progeny of the two groups, reared under the same conditions, can be compared with each other and with their parents.   Meristic characters, such as head and snout length, vertebral count, gill raker count and scale count, together with egg diameter, growth rate and state of maturity of adults during their return migration will be used to assess the possibility of these characters being heritable.

Marked summer and winter juveniles (age 1+) have already been planted in Capilano River (1958, 1960).   Returns of adult fish from these plantings will provide information of the tendency (if any) for individuals of these two groups to follow the parental pattern of "summer" or "winter" development.   To the present time (April, 1960), 14 marked adults from the 1958 planting of winter-stock smolts have been recaptured in the Capilano, and all were as sexually mature as their parents upon entry to the trapping facilities.   Five marked adults from the 1958 planting of summer-stock smolts also have been recaptured.   All specimens of this latter group were immature sexually and, like their parents, they are being held until fully mature, when they will be spawned artificially.

Since none of the summer steelheads' progeny returned as winter fish, and none of the winter steelheads' progeny as summer fish, it does not seem premature to believe that a strongly heritable difference exists between these two stocks of steelheads from Capilano River.   Morphological comparisons are being carried out on both the adults and their offspring, which will be reported at a later date.

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